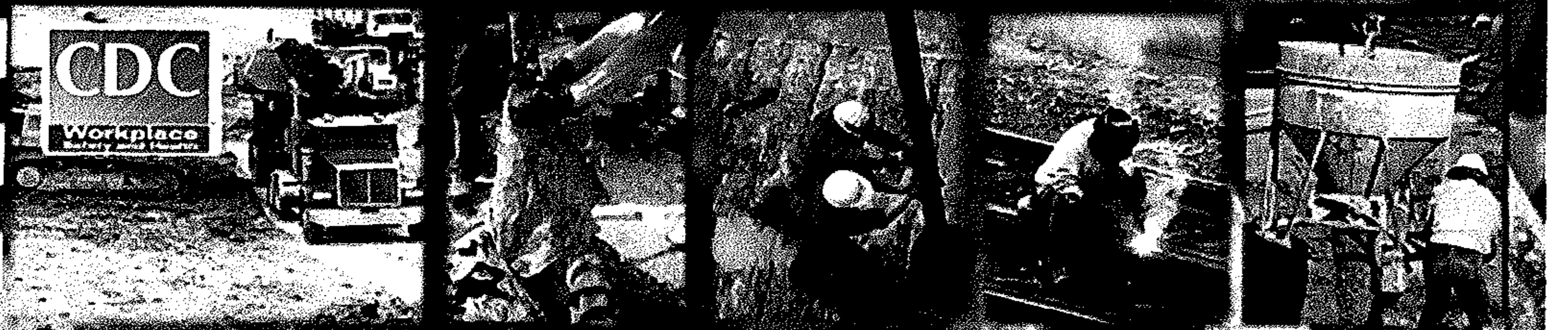
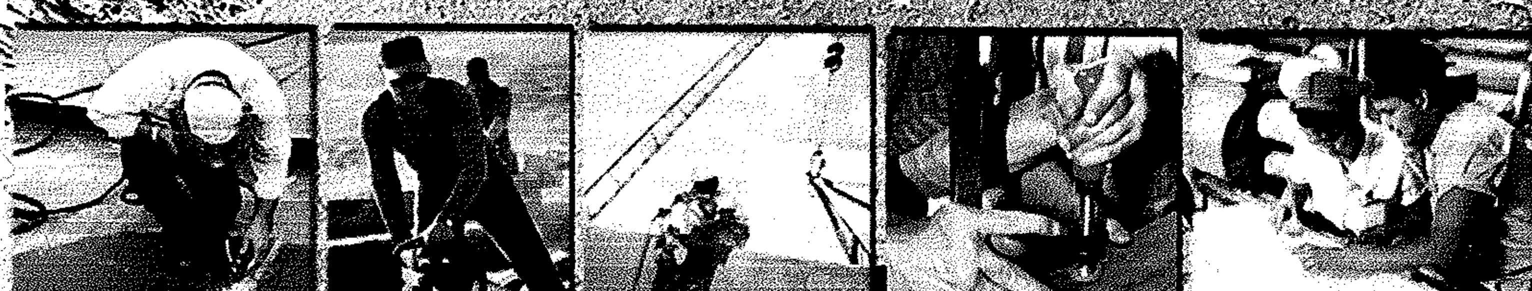
P



Proceedings of the First American Conference on Human Vibration



DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

National Institute for Occupational Safety and Health
NIOSH

Proceedings of the

First American Conference on Human Vibration

June 5-7, 2006

Waterfront Place Hotel
Morgantown, West Virginia, U.S.A.

Ren Dong, Ph.D.
Kristine Krajnak, Ph.D.
Oliver Wirth, Ph.D.
John Wu, Ph.D.

Engineering and Control Technology Branch
Health Effects Laboratory Division
Morgantown, West Virginia, U.S.A.

Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Disclaimer

Mention of any company or product does not constitute endorsement by NIOSH. In addition, citations to Web sites external to NIOSH do not constitute NIOSH endorsement of the sponsoring organizations or their programs or products. Furthermore, NIOSH is not responsible for the content of these Web sites. The findings and conclusions in this report have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy.

ORDERING INFORMATION

To receive documents or other information about occupational safety and health topics, contact NIOSH at

NIOSH – Publications Dissemination
4676 Columbia Parkway
Cincinnati, OH 45226-1998

Telephone: 1-800-35-NIOSH (1-800-356-4674)
Fax: 513-533-8573
E-mail: pubstaft@cdc.gov

Or visit the NIOSH Web site at www.cdc.gov/niosh

DHHS (NIOSH) Publication No. 2006-140
June, 2006

Foreword

It is my pleasure to welcome the First American Conference on Human Vibration to Morgantown, West Virginia. This meeting showcased the most recent research regarding the physiological effects of vibration. It explored the etiology of vibration-induced disorders and illuminated opportunities for their diagnoses, treatment, and prevention.

Vibration-induced disorders, such as work-related Reynaud's disease, are serious and potentially disabling. They may result in loss of feeling and interfere with one's ability to work. NIOSH has long sought strategies to prevent vibration-induced disorders. In 1983 the Institute published a Criteria Document describing the risk of vibration syndrome from the use of hand-held machinery. Since that time the body of knowledge in this field has continued to expand. We now better understand the risk faced by workers who drive on or off road vehicles, operate marine or aircraft, or are exposed to continuous building vibration.

This conference provided us with a historic opportunity to exchange information regarding this critical occupational health issue. The agenda promised a rich and diverse scientific program as researchers and medical professionals from around the world have gathered to examine human responses to hand-transmitted vibration and whole-body vibration.

NIOSH is pleased to have hosted the first U.S. conference to examine human vibration, and I would like to thank the many scientific presenters from both the U.S. and abroad who have come to share their work with us. Together, we will advance the science further and achieve safer and healthier workplaces.

I congratulate you on a successful conference.

John Howard, MD
Director, National Institute for Occupational Safety and Health

Acknowledgments

The convening of the First American Conference on Human Vibration was supported by the Health Effects Laboratory Division of the National Institute for Occupational Safety and Health (NIOSH). Many thanks to Frank J. Hearl (Chief of Staff, NIOSH) for delivering the opening address. Assistance with the organization of the conference was provided by Jamie Long (West Virginia University -- Continuing Education) and Barbara Elbon, Thomas McDowell, Daniel Welcome, and Christopher Warren (NIOSH). Editing, cover design, graphics, and layout were provided by Kimberly Clough Thomas (NIOSH). Tanya Headley (NIOSH) provided assistance with the final editing.

ACHV Organizing Committee

Ren Dong[1]
Chuanfang Jin[4]
Kumar Kittusamy[2]
Kristine Krajnak[1]
Alan Mayton[3]
Oliver Wirth[1]
John Wu[1]

[1] Health Effects Laboratory Division, National Institute for Occupational Safety and Health
[2] Spokane Research Laboratory, National Institute for Occupational Safety and Health
[3] Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health
[4] School of Medicine, West Virginia University

Board of Scientific Advisors (in alphabetical order)

Table of Contents

Introduction

Vibrations caused by power tools, machinery, vehicles, and heavy equipment are a ubiquitous feature of modern work environments. In the U.S., an estimated six million workers are in occupations exposed to whole-body vibration and more than one million workers are in occupations exposed to hand-transmitted vibration (U.S. Bureau of Labor Statistics, 2004). Since Alice Hamilton's seminal report in 1918 on vibration-induced hand disorders in quarry stonecutters, the potential health risks associated with prolonged and repeated vibration exposure have been well recognized and documented. Efforts to understand the exposure risk factors and adverse health effects of occupational vibration exposure have waxed and waned over the years. Despite numerous studies and technological advances in vibration measurement and control, the exposure risks and etiology of the adverse health effects are not well understood. Human exposure to vibration remains a major risk factor associated with vascular, neural, and musculoskeletal disorders.

The First American Conference on Human Vibration (ACHV) was held in Morgantown, West Virginia, June 5-7, 2006. It was organized by the Health Effects Laboratory Division of the National Institute for Occupational Safety and Health and West Virginia University Department of Continuing Education. This conference provided a unique opportunity for a multidisciplinary group of national and international experts to exchange current information on all aspects of segmental and whole-body vibration exposures. The attendees included industrial hygienists, engineers, physicians, epidemiologists, scientists, psychologists, physiologists, health and safety specialists, consultants, students, and other individuals from Government, industry, and academic institutions from the U.S., Canada, and more than seven other countries.

Four keynote lectures and more than 60 papers were presented at this conference. Topics included vibration exposure measurement and quantification, biodynamic responses of whole-body and hand-arm system, subjective perceptions of vibration, physiological and pathological mechanisms, health effects, clinical diagnoses, epidemiological studies, prevention effectiveness, standard development and implementation. Presentations also described recent technological advances that may improve vibration measurement, tool and vehicle seat designs and tests, personal protection devices, and clinical diagnosis and assessment methods.

The ACHV was intended to prompt the convening of future, biennial conferences on human vibration in North America. We hope that the publication of these conference proceedings will help encourage new research and technological advances so that the health hazards associated with occupation vibration exposures will be significantly reduced.

Ren Dong
Kristine Krajnak
Oliver Wirth
John Wu

Morgantown, West Virginia

Keynote Speakers

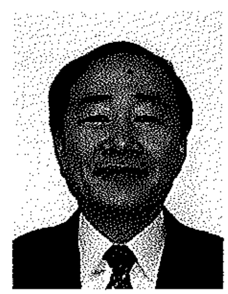
Michael J. Griffin

Michel Griffin, BSc., Ph.D., is the head of the multi-disciplinary Human Factors Research Unit in the Institute for Sound and Vibration Research at the University of Southampton in England. Professor Griffin is the Chairman of the British Standards Institution Sub-Committee concerned with human response to mechanical vibration and shock. He is also a member of relevant committees of the International Organization for Standardization and the European Committee for Standardization. Professor Griffin has particular research interests in biodynamics, human performance, ride comfort in vehicles, vibration-induced injuries, and motion sickness.

Setsuo Maeda and Neil J. Mansfield

Setsuo Maeda, Dr.Eng., Dr.Med.Sci. is the Director of Department of Hazard Assessment at Japan National Institute of Occupational Safety and Health in Kawasaki, Japan. His research interests include human response to multi-axis whole-body vibration and multi-axis hand-arm vibration. Neil Mansfield, B.Eng., Ph.D., is a Senior Lecturer in the Department of Human Sciences at Loughborough University in the U.K. He is Technical Director of OPERC hand-arm vibration test centre (HAVTEC) and heads the Vibration, Biomechanics and Noise research group of Loughborough University's Environmental Ergonomics Research Centre. He has worked in the area of human response to vibration and noise for 15 years as a consultant.

Hisataka Sakakibara



Hisataka Sakakibara, M.D., Ph.D. is a Professor at Nagoya University School of Health Sciences in Nagoya, Japan. His major research focuses on the pathophysiological effects of hand-arm vibration.

Chris Nelson

Chris Nelson, Ph.D. is a Specialist Inspector (Noise and Vibration) with the U.K.'s Health and Safety Executive (HSE). He has recently been involved with the development of British legislation, and supporting guidance, to implement the European vibration directive. He is also convener of the ISO and CEN working groups on hand-arm vibration. Prior to joining the HSE, Chris spent some years involved in research and consultancy work at the Institute of Sound and Vibration Research, Southampton University, gaining a Ph.D. for his study of vibration-induced white finger in dockyard employees. He then joined the Institute of Naval Medicine as Head of Acoustics and Vibration, moving to the HSE in 1997.

Keynote Presentation

HEALTH EFFECTS OF VIBRATION – THE KNOWN AND THE UNKNOWN

Michael J. Griffin
Institute of Sound and Vibration Research, University of Southampton, U.K.

Introduction

Science involves the study of the nature and behaviour of natural things and the knowledge we obtain about them. Scientific endeavour leads to the unfolding of new knowledge and adjustments to our understanding and our behavior. To indicate that we 'know' something may merely mean we do not feel able to, or that we do not wish to, disagree with others who claim to know; or it may mean we have either heard about it, or studied it, or understand part of it, or accept that it is true, or have seen evidence to be convinced of its veracity. What do we 'know' about the health effects of vibration?

There are many unknowns in the field of human responses to vibration. Not all would agree on what is known and what is unknown. This paper seeks to summarize what we know that we know, what it is sometimes claimed that we know, and what we know that we do not know about the relation between exposures to vibration and our health. It also speculates on what we do not know that we do not know.

Hand-transmitted vibration

What we know we know

We know that exposures to hand-transmitted vibration result in various disorders of the hand, including abnormal vascular and neurological function. Not all frequencies, or magnitudes, or durations, of hand-transmitted vibration cause the same effects.

What we may claim to know

To enable exposures to be reported and compared, they are 'measured' and 'evaluated' using defined (e.g. standardised) procedures. This involves identifying what is to be measured and specifying how it is expressed by one (or a few) numbers. Summarising a vibration exposure in a single value involves assuming the relative importance of components within the vibration (e.g. different magnitudes, frequencies, directions, and durations), so standards define 'weightings' for these variables. The importance of the weighted values may also be suggested, allowing 'assessments' according to a criterion (e.g. the probability of a specific severity of a specific disease).

Standards for the measurement and evaluation of hand-transmitted vibration define a frequency weighting and time dependencies that allow the severity of vibration exposures to be assessed and the probability of finger blanching to be predicted [1].

What we do not know

We do not know that the frequency weighting in current standards reflects the relative importance of different frequencies and axes of vibration in producing any specific disorder. We do not know whether the energy-based daily time-dependency inherent in A(8) reflects the relative importance of vibration magnitude and daily exposure duration. Consequently, the relation between A(8) and the years of exposure to develop finger blanching, as in an appendix to ISO 5349-1 (2001), is not well-founded.

We do not know, or at least there is no consensus on, the full extent of the disorders caused by hand-transmitted vibration (e.g. vascular, neurological, muscular, articular, central), or the pathogenesis of any specific disorder caused by hand-transmitted vibration, or the roles of other factors (e.g. ergonomic factors, environmental factors, or individual factors). We know that acute

exposures to hand-transmitted vibration cause both vascular and neurological changes analogous to the changes seen in those occupationally exposed to hand-transmitted vibration, but we do not yet know how the acute changes relate to the chronic disorders.

Whole-body vibration

What we know we know

We know that many persons experience back pain and that some of these are exposed to whole-body vibration. We know that in the population at large, occupational exposures to whole-body vibration are not the main cause of back problems, and that ergonomic factors (e.g. lifting and twisting) and personal factors are often involved. We know vibration and shock can impose stresses that could supplement other stresses.

What we may claim to know

Measurement methods and evaluation methods have been defined in which the frequencies, directions and durations are weighted so as to predict the relative severity of different vibrations and indicate the magnitudes that might be hazardous [2].

What we do not know

We are not able to predict the probability of any disorder from the severity of an exposure to whole-body vibration. We do not know whether there is any disorder specific to whole-body vibration, or what disorders are aggravated by exposure to whole-body vibration. We do not know the relative importance of vibration and other risk factors in the development of back disorders.

Discussion

Providing guidance to others involves compromises – a perceived need, or other argument, may outweigh the cautious interpretation of scientific evidence. Standards for measuring and evaluating human exposures to vibration use uncertain frequency weightings and time dependencies but allow legislation for the protection of those exposed [3]. The standards may appear useful, but it is prudent to distinguish between standards and knowledge – between what is accepted to reach a consensus and what can be accepted as proven. Standards may guide actions but not understanding.

Where reducing risk solely involves reducing vibration magnitude or exposure duration, ill-founded evaluation methods will not increase risk. Where prevention involves a redistribution of vibration over frequencies or directions, or balancing a change in magnitude with a change in duration, an inappropriate evaluation method can increase risk. For example, the hand-transmitted vibration frequency weighting, which may be far from optimum, implies that gloves give little beneficial attenuation, whereas a different weighting might indicate that gloves can be a useful means of protection [4].

What do we not know that we need to know? Not all appreciate the benefits of placing more reliance on traceable data than on consensus. Traceability is fundamental to quality systems but deficient in current standardization. Standards can comfort their users – justifying actions without resort to understanding – while concealing assumptions that may prevent the minimization of the risks of injury from exposures to vibration.

References

1. International Organization for Standardization (2001) Mechanical vibration - measurement and evaluation of human exposure to hand-transmitted vibration - Part 1: General requirements. ISO 5349-1.

2. International Organization for Standardization (1997) Mechanical vibration and shock - evaluation of human exposure - to whole-body vibration. Part 1: general requirements. ISO 2631-1.

3. Griffin, M.J. (2004) Minimum health and safety requirements for workers exposed to hand-transmitted vibration and whole-body vibration in the European Union; a review. Occupational and Environmental Medicine; 61, 387-397.

4. Griffin, M.J. (1998) Evaluating the effectiveness of gloves in reducing the hazards of hand-transmitted vibration. Occupational and Environmental Medicine, 55, (5), 340-348.

Keynote Presentation

EVALUATION OF WHOLE-BODY VIBRATION COMFORT

Setsuo Maeda, National Institute of Industrial Health, Kawasaki, Japan
Neil J Mansfield, Loughborough University, Loughborough, U.K

Introduction

The purpose of using experimental subjective and/or perception methods is: (a) to understand human subjective impressions of the physical characteristics of vibration; (b) to determine the relationship between the subjective perception of some aspect of the vibration and an evaluation index of the physical vibration characteristics; and (c) the establishment of target values for design of vibration environments in terms of human sensation of vibration characteristics. In order to understand the relationship between a physical measure of the mechanical vibration and the subjectively perceived aspect of the vibration environment, experimental methods shown in Table 1 have been used[1].

Table 1. Psychophysical methods.

Constant measurement methods	Constant stimulus method Method of adjustment Method of limits Adaptive psychological method
Subjective scaling methods	Interval scale Paired comparison method Category judgment method Proportional scale Magnitude estimation

The constant measurement methods of Table 1 are mainly used for measurement of the threshold of human sense. The subjective scaling methods are mainly used for obtaining subjective (or proportional) scaling between the perceived quantity and physical quantity.

In this review, the fundamental approach of experimental methods for obtaining the target values used in the design of vibration environments, and the different findings between the subjectively perceived methods for evaluating human response to vibration characteristics and the physical quantity of the vibration environment are summarized.

Fundamentals of Subjective Scaling

The relationship between the experimental psychological methods for providing target values in the design of the vibration environments and the physical quantities is illustrated in Fig. 1. Vehicle mechanical vibration can be characterized using many metrics, and these can be considered the 'input' to the human. In order to predict subjective responses to the vibration, it is necessary to link the characteristics of the source of vibration and human reactions, the 'output'.

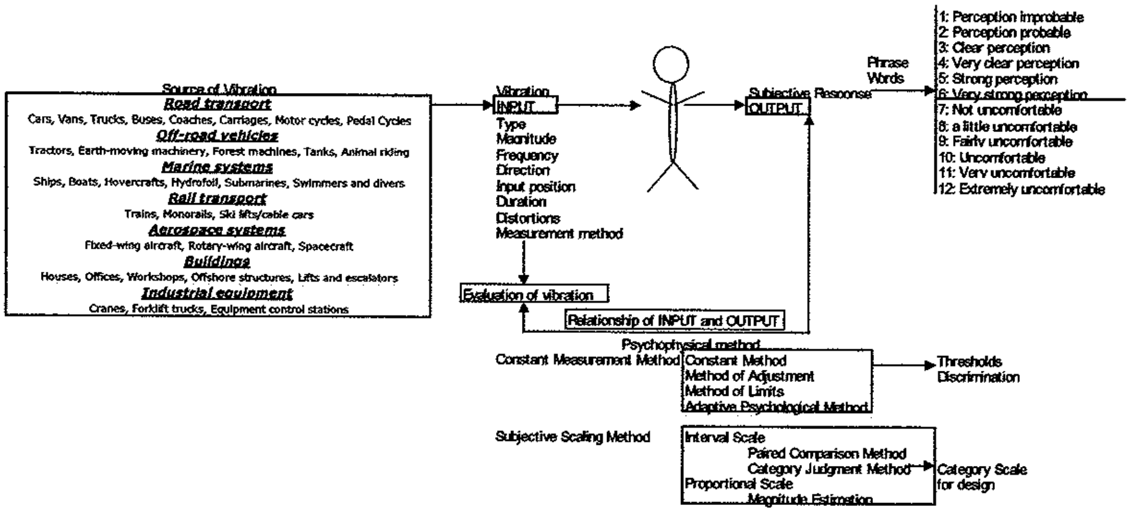


Fig.1 Relationship between vibration and subjective responses.

The constant measurement methods are usually used when the aim of the research is to understand human sensation in response to changes in the nature of the vibration (e.g. changes in frequency). The constant method uses an array of predetermined stimuli at discrete magnitudes above and below the expected threshold; the method of adjustment allows the experimental subject to control the magnitude such that they can set it to their threshold; the method of limits alternates the magnitude between detection and non-detection thresholds; adaptive methods use stimuli with magnitudes which step up and down, crossing the threshold, in response to subjective responses. In all of these cases the threshold could be absolute perception or some form of difference threshold.

Subjective scaling, such as using interval scales or proportional scales, has usually been used when the aim of the research is to understand human sensation in response to changes in the perceived magnitude of vibration. Paired comparisons requires subjects to choose one of two stimuli (e.g. greater intensity); category judgment requires subjects to select from a range of text descriptors (e.g. describing levels of discomfort); magnitude estimation requires subjects to give a numerical score to each stimulus. Some methods are used that try to combine qualities from more than one technique (e.g. Borg CR-100).

Each experimental method works in a different way and has its own advantages and disadvantages. Therefore, researchers must carefully choose the most appropriate experimental method. It is also essential to include enough information for readers to understand and assess the methods used when presenting and publishing results.

It will be necessary to conduct new experiments for the design of vehicles in the future, possibly requiring new psychophysical approaches. For example, new methods might be required to investigate the relationship between the human biodynamic response and subjective responses to multi-axis whole-body vibration.

Reference

1. Guilford J.P. (1954) Psychometric methods. McGraw-Hill, New York.

Keynote Presentation

SOME ASPECTS OF PATHOGENESIS OF VIBRATION-INDUCED WHITE FINGER

Hisataka Sakakibara
Nagoya University School of Health Sciences, Nagoya, Japan

Introduction

Although the pathophysiology of vibration-induced white finger (VWF) is still under discussion, evidence has been accumulated to understand the underlying mechanism.

VWF is pathophysiologically characterized by an enhanced vasospastic response to cold, which can result from an imbalance between vasoconstriction and vasodilation in the digital arteries in response to cold (i.e., vasoconstriction-dominant). The imbalance is supposed to be due to faults in vascular vessels and sympathetically mediated vascular tone.

Enhanced vasospastic response to cold

Structural factors for enhanced vasoconstriction (and vasodilation)

- Narrowing of arterial lumen with medial smooth muscle hypertrophy.

Possible functional factors for enhanced vasoconstriction

- Increased sympathetic nervous activity to cold (e.g., norepinephrine)
- Increased release of endothelin-1 (ET-1; an endothelial-dependent vasoconstrictor) from the endothelium
- Increased reactivity of alpha2-adrenoreceptors to cold

Possible functional factors for decreased vasodilation

- Decreased release of nitric oxide (NO; an endothelial-dependent vasodilator) from the endothelium
- Decreased release of calcitonin gene-related peptide (CGRP; a vasodilatory neuropeptide) from sensory afferents

The question is how their interrelations or imbalances among them are.

Vibration and arterial damage

The next question is, how does hand-arm vibration exposure induce such pathophysiological changes in VWF patients? Recent morphological evidence from animal experiments shows that vibration acceleration stress (including shear stress) and smooth muscle contraction contribute to arterial damage of smooth muscle and endothelial cells. The vibration-induced arterial damage is frequency-amplitude-dependent.

Repeated vibration exposure may damage smooth muscle cells to medial hypertrophy leading to lumen narrowing and injure endothelial cells to impaired vasodilation, resulting in vasospastic response to cold. The enhanced vasospastic response might in turn exaggerate vasoconstriction in response to cold.

References

Sakakibara H. (1998). Pathophysiology and pathogenesis of circulatory, neurological, and musculoskeletal disturbances in hand-arm vibration syndrome. In: Pelmear PL, Wasserman DE (eds) Hand-Arm Vibration, A Comprehensive Guide for Occupational Health Professionals (Second Edition), Beverly Farms, OEM Press.

Herrick AL (2005). Pathogenesis of Raynaud's phenomenon. Rheumatol. 44, 587-596.

Curry BD, Govindaraju SR, Bain JLW, Zhang LL, Yan J-G, Matloub HS, Riley DA (2005). Evidence for frequency-dependent arterial damage in vibrated rat tails. Anat. Record Part A 284A, 511-521.

Keynote Presentation

EUROPEAN LEGISLATION AND STANDARDISATION FOR THE CONTROL OF RISKS FROM VIBRATION AT WORK

Chris Nelson
Health and Safety Executive, United Kingdom

Introduction

Two pieces of European Union (EU) legislation together establish requirements for protection against risks from vibration at work. The vibration directive[1] specifies duties of employers to protect workers from risks from exposure to vibration; the machinery directive[2], specifies duties of manufacturers and suppliers regarding the safety of machinery marketed in the EU. This paper discusses both directives and the standardisation programmes that support them. It also addresses the implementation of these requirements in Great Britain.

Employers' duties: the vibration directive

This directive requires employers to assess and control risks to health and safety arising from hand-arm vibration (HAV) and whole-body vibration (WBV). Member States were required to implement the directive in national legislation by 6 July 2005.

Employers are required to eliminate vibration risk at source, or reduced to a minimum. The duties include: assessing risk and exposure; planning and implementing the necessary risk control measures; providing and maintaining suitable work equipment; providing workers with information and training on risks and their control; and monitoring and reviewing the effectiveness of the risk control programme. Daily exposure exceeding a specified action value triggers a requirement for a programme of technical and organisational measures to minimise vibration exposures and the resulting risk, and the provision of health surveillance. Exposures above a specified limit value are prohibited.

When conducting their risk assessments, employers are required to "assess and, if necessary, measure" the vibration exposure of workers, for comparison with the action and limit values. Vibration measurement in the workplace is not expected in all cases and the use of vibration information from equipment manufacturers is specifically mentioned. This provides a link with the machinery directive (see below).

Manufacturers' and suppliers' duties: The machinery directive

The machinery directive, first introduced in 1989, is intended to remove barriers to trade. It puts duties on manufacturers and suppliers who place machinery on the European market to design their products to eliminate or reduce risks to health and safety and to warn the user of any residual risks, providing information required for safe use (for example, operator training, maintenance and selection of consumables). There are specific requirements for minimising risk from vibration in the design and construction of the machine and, in the case of hand-held, hand-

guided and mobile machines, for declaring the vibration emission. If the declared emission of a machine is representative of the vibration in real-world use, it can be adequate to inform the user of residual vibration risks.

Standards supporting the two directives

The vibration directive contains two annexes (for HAV and WBV respectively) which define the metrics for daily vibration exposure by reference to ISO 5349-1:2001 for HAV and ISO 2631-1:1997 for WBV. The European Standards bodies (CEN and CENELEC) have no mandate from the European Commission to produce any standards in support of the vibration directive. However, CEN had, in 2001, adopted both parts of ISO 5349, and has also chosen to prepare a new standard providing guidance on assessing daily WBV exposures using the "A(8)" method.

The machinery directive is supported by a set of harmonized standards, mostly prepared by CEN and CENELEC under a work programme mandated by the European Commission. Where appropriate, this is done in partnership with ISO so that the relevant international standard is used to support the directive in Europe. The harmonized standards define safety requirements for various categories of machine (including the provision of user information); conformity with the relevant standard carries a presumption of conformity with the directive. The standards include test codes for vibration emission; some of those dealing with hand-operated equipment do not adequately describe the vibration in typical use and require revision.

Controlling risks from vibration at work in Great Britain

Both directives are implemented as regulations in the British legal system and are enforced by the Health and Safety Executive (HSE). HSE's work programme includes targeted inspections of high-risk activities (currently focusing on construction, foundries and steel fabrication) to ensure that HAV risks are properly controlled. Visits to tool manufacturers and suppliers are also undertaken, to secure improved provision of information on vibration risks. This front-line work is supported by the production of guidance material and activities to communicate HSE's messages on preventing vibration-related ill-health[3].

References

1. European Parliament and the Council of the European Union (2002) Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration). Official Journal of the European Communities, OJ L177, 6.7.2002, 13.

2. Council of the European Union (1998) Council Directive 98/37/EC on the approximation of the laws of the Member States relating to machinery. Official Journal of the European Communities, OJ L207, 23.7.98, 1-46.

3. HSE's vibration web pages. www.hse.gov.uk/vibration

Podium Presentations

Session I: Exposure I

Chairs: Suhbash Rakheja and Logan Mullinix

USING AN AIR BLADDER SEAT SHOCK ISOLATION SYSTEM TO PROTECT MILITARY VEHICLE OCCUPANTS FROM MINE BLASTS

Douglas D. Reynolds, Qunli Liu, Tarek Deeb
Center for Mechanical & Environmental Systems Technology,
University of Nevada Las Vegas, Las Vegas, Nevada, U.S.A.

Introduction

Landmines are a great threat to military vehicles and their occupants. Mine blasts can completely destroy vehicles and kill all the occupants or disable the vehicle and leave the occupants severely injured. Injuries sustained during a landmine blast come from fragmentation that enters the vehicle through a hull breach, hot gasses expanding through the vehicle, or shock created from the extreme pressure of the blast (Lafrance, L.P. 1998). Mitigating the high acceleration experienced by the occupants during survivable mine blasts is the focus of the research being addressed in this paper.

Method

The objective of the project reported in this paper was to prove the feasibility that pneumatic seat technologies that employ light-weight, foam-filled, inflatable air bladder seats and seat backs can be used to protect the crews of lightweight combat vehicles against the detrimental and injurious effects of mine blasts. This protection includes reducing the shock energy experienced by seated vehicle crews during mine blast initiation and at vehicle slam-down to below potentially injurious levels. Figure 1 shows a schematic representation of the proposed lightweight, foam-filled, inflatable mine blast attenuating seat. It will consist of specially designed interconnected seat and seat back lightweight, foam-filed, air bladders that are supported by a rigid frame.

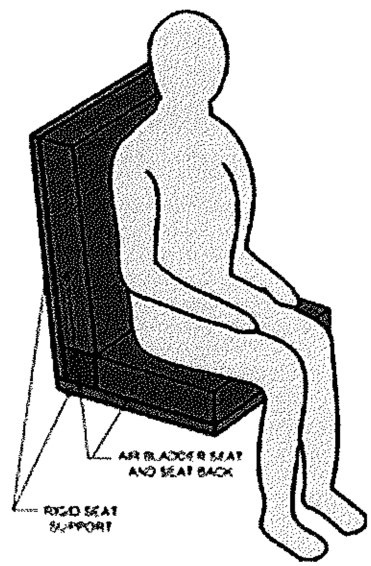


Figure 1 Schematic of Lightweight, Foam-Filled Inflatable Mine Blast Attenuating Seat

Results

Air gun tests and finite element analyses were conducted to determine the effectiveness of a light-weight, foam-filled, inflatable air bladder seat shock isolation system in isolating a vehicle occupant from the injurious effects of a mine blast. Figures 2 through 5 show analytical and experimental results associated with a 65.8 kg mass resting on an inflatable air bladder that is exposed to a shock input.

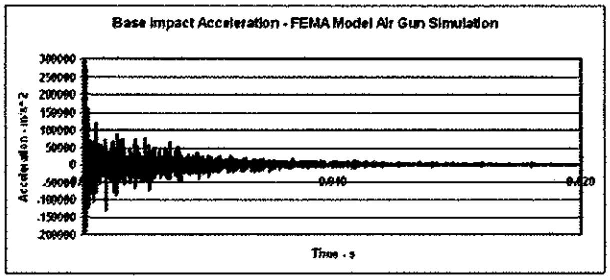


Figure 2 Simulated Air Gun Test Shock Input

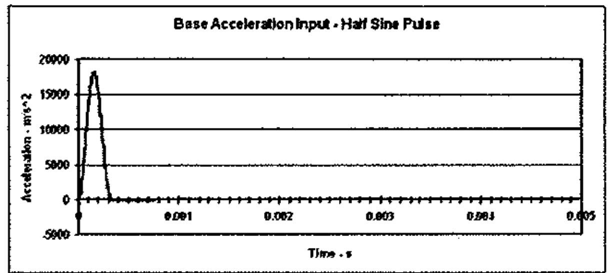


Figure 3 0.32 ms 8,000 m/s^2 Half-Sine Shock Input

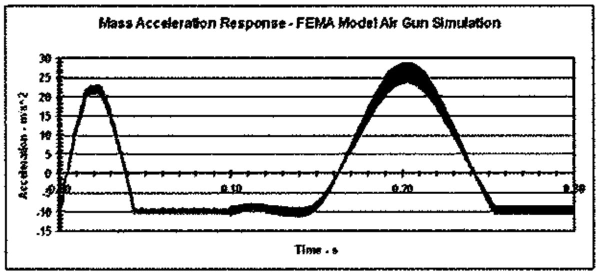


Figure 4 Supported Mass Acceleration – Air Gun Simulation

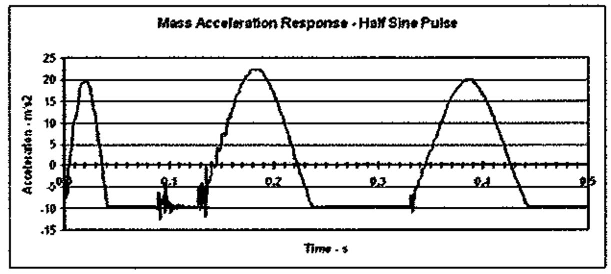


Figure 5 Supported Mass Acceleration – 0.32 ms 18,000 m/s^2 Half-Sine Pulse Input

Discussion

Table 1 shows that seat bladder reduced the peak acceleration response of the 65.8 kg mass relative to the peak shock input acceleration by three orders of magnitude for the air gun test and the half-sine shock pulse simulation.

The seat bladder shock isolation system has the potential when properly and fully developed to significantly reduce the injurious effects of mine blast shock inputs to seated individuals in lightweight combat vehicles.

Ubcmf!2! TfbuCmbeefs!Tipdl !Buufovbujpo!Sftvmut!

!!	!	Tvqqpsu N btt! Jn qbdu Bddfmfsbujpo	76/9!! h! n btt!Qfbl ! Bddfmfsbujpo	76/9!! h!N btt! Bddfmfsbujpo0Tvqqpsu N btt!Bddfmfsbujpo!
!!	!	n 0^3	n 0^3	!!
31!qtj!Bjs!Hvo!Ubol !Qsfttvsf!		45-111!	58!	1/112!
Tjn vmbuf e!Bjs!Hvo!Uftu	!	39-111!	36!	1/112!
1/43!n t!! bmgTjof!Qvmtf!TfbuJn qbdu	!	29-111!	34!	1/112!

!

References

Lafrance, L.P., 1998, "Mine Blast Protection Systems for Military Support." American Society of Mechanical Engineers, vol. 361 pp. 305-309.

VIBRATION SPECTRAL CLASS CHARACTERIZATION OF LONG HAUL DUMP MINING VEHICLES AND SEAT PERFORMANCE EVALUATION

P.-É. Boileau[1], J. Boutin[1], T. Eger[2] and M. Smets[2]
[1]Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), Montréal, Canada
[2]School of Human Kinetics, Laurentian University, Sudbury, Canada

Introduction

Long-haul dump (LHD) vehicles used in underground mining are known to expose workers to important levels of whole-body vibration[1]. These vehicles are generally designed without suspension and may be categorized as small or large LHDs depending on whether their respective load capacities are lower or larger than 3.5 cubic yards. While the majority of older vehicles are equipped with a rigid or unsuspended seat, more recent LHDs often incorporate a suspension seat.

The objective of this study was to define the vibration spectral characteristics of most commonly encountered large and small LHD vehicles operating in mining operations. This was done in an effort to categorize the vehicles in terms of vibration spectral classes to be reproduced on a laboratory whole-body vibration simulator to assess the vibration attenuation performance of a typical LHD suspension seat.

Methods

Vertical vibration measured at the seat attachment point of 8 small and 8 large LHD vehicles operating underground in typical mining operations under loaded and unloaded conditions was considered as the basis for defining the spectral classes. By regrouping the data collected for each LHD vehicle size and load condition, the overall distribution of acceleration power spectral density (PSD) of measured floor vibration was determined over the 0.5 to 20 Hz frequency range. Mean and envelopes of maximum and minimum values of PSD spectra were computed to define the spectral classes, along with the corresponding values of frequency weighted rms acceleration determined in accordance to the ISO 2631-1 standard[2]. These spectra were further used to calculate the displacements needed to drive a whole-body vibration simulator consisting of a platform supported by two servo-hydraulic actuators having a total stroke of ±100 mm. For validation purposes, the vibration acceleration spectra measured on the simulator were compared with the target spectra representing the spectral classes. Finally, the vibration transmissibility characteristics of a typical suspension seat were determined under sine sweep excitation using both a rigid mass load and a human subject having a mass of 62 kg and 85 kg, respectively. The SEAT value, representing the ratio of seat to base frequency-weighted rms acceleration, was further measured under each of the defined LHD vibration spectral classes by loading the seat with an 85 kg subject. Tests were repeated three times and the mean SEAT values were determined to assess the seat's ability to reduce exposure to whole-body vibration in LHD vehicles.

Results

Three spectral classes applicable to both loaded and unloaded conditions were defined as shown in Figure 1: one for large and two for small LHDs. The influence of load on frequency-weighted rms acceleration was found to be negligible for large and Class I small LHDs, while a shift of the peak acceleration PSD to lower frequencies was noted for the loaded vehicles. The influence of load was found to be more important for Class II small LHDs. Table 1 provides a

comparison of frequency weighted, a_w, and unweighted, a, accelerations and dominant frequencies for the mean, maximum and minimum spectra associated with the different spectral classes. These were reproduced on a vibration simulator and used to assess the performance of a typical LHD suspension seat. The results obtained suggest that the seat cannot provide attenuation of the vibration at the dominant frequencies of the vehicles which range from 2.6 to 3.4 Hz . The measured SEAT values ranging from 1.25 for large LHDs to 1.35 for Class II small LHDs confirm that the seat is not adapted to these vehicles.

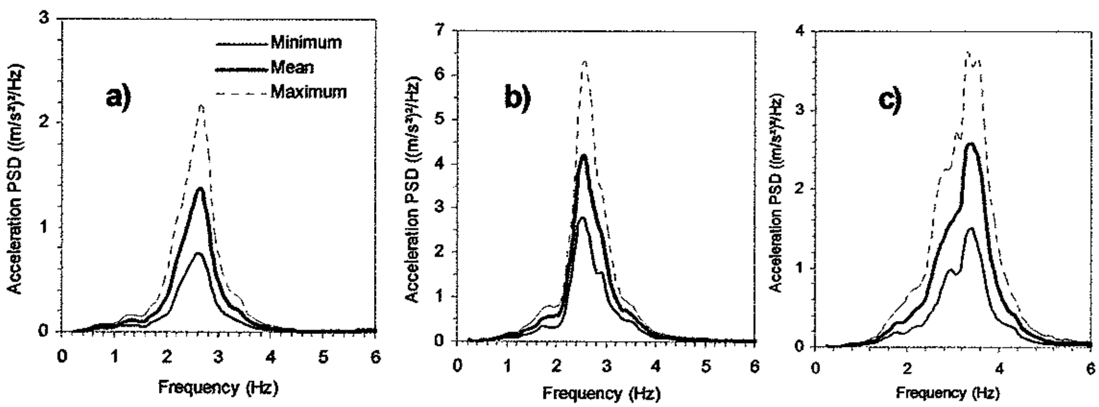


Figure 1 : Vibration spectral classes :a) Large LHDs; b) small LHDS Class I ; c) small LHDs Class II

Table 1: Characteristics of the spectral classes for large and small LHDs.

Spectrum	Large LHDs		Small LHDs-Class I		Small LHDs-Class II	
	a	a_w	a	a_w	a	a_w
Minimum (ms^{-2})	0.89	0.62	1.63	1.16	1.38	1.13
Mean (ms^{-2})	1.20	0.85	2.03	1.45	1.88	1.55
Maximum (ms^{-2})	1.52	1.09	2.45	1.76	2.36	1.95
Dominant frequency	2.7 Hz		2.7 Hz		3.4 Hz	

Discussion

The vibration measured in LHD vehicles can be categorized into three spectral classes, two of which apply to small LHDs. In general, small LHDs lead to much higher vibration levels than large LHDs and the spread of values is more important, particularly for class II vehicles for which the dominant vibration frequency is considerably higher than that of the other categories. Laboratory evaluation of a typical suspension seat recommended for use in these vehicles has shown that it is more likely to provide amplification of whole-body vibration under normal operating conditions.

Acknowledgment

The authors would like to extend their gratitude to the WSIB of Ontario and IRSST for funding this part of the research project.

References

1. Village, J., Morrison, J., Leong, D. (1989). Whole-body vibration in underground load-haul-dump vehicles, Ergonomics. 32(10), 1167-1183.
2. International Standard ISO 2631-1 (1997). Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part 1: General requirements.

TIME-FREQUENCY ANALYSIS OF HAND-TRANSMITTED VIBRATION OF IMPACT TOOLS USING ANALYTIC WAVELET TRANSFORM

Jay Kim,[1] Daniel E. Welcome,[2] Ren G. Dong,[2]
Won Joon Song,[1] Charles Hayden[2]
[1]Mechanical, Industrial and Nuclear Engineering Department
University of Cincinnati, Cincinnati, Ohio, U.S.A.
[2]National Institute for Occupational Safety and Health
Morgantown, West Virginia, U.S.A.

Introduction

Prolonged, extensive exposure to hand-transmitted vibration could cause a series of vibration-induced disorders in the vascular, sensorineural, and musculoskeletal structures of the human hand-arm system, which have been collectively called hand-arm vibration syndrome (HAVS).[1] To assess the risk of HAVS the international standard ISO 5349-1 (2001)[1] recommends using the root-mean-square (rms) acceleration of the measured vibration with a frequency weighting. While a few epidemiological studies have reported results consistent with the predictions made according to the recommendation, many other studies have reported results with large discrepancies.[2] This may be partially attributed to the time-averaging effect involved in calculation of the frequency components, especially for impact type tools. Because the spectral characteristics of impact tools change dramatically with time, a time-frequency (T-F) analysis can provide better characterizations of such highly transient vibrations. The analytic wavelet transform (AWT) is an ideal T-F analysis tool because it possesses the advantages of both the Fourier transform and the wavelet transform.[3] The objective of this study was to explore the application of the AWT method for characterizing the impact tool vibrations and assessing their exposure risk.

Methods

Five tools (two chipping hammers, two riveting hammers, and one concrete cutting saw) were used in this study. The saw vibration was measured when it was used to cut a section of road pavement during a repair. The vibrations on the other tools were measured by the procedure specified in ISO 8662-2 (1992).[4] A sampling rate of 16,386 Hz was used in the measurement. The AWT and Fourier analysis were applied to these signals and to identify their characteristics.

Results

Figure 1 compares the T-F characteristics of the accelerations measured from the relatively steady concrete saw and a riveting hammer. The frequency weighting specified in ISO 5349-1[1] was applied in the calculations. The comparison clearly shows that the two tools have completely different T-F characteristics.

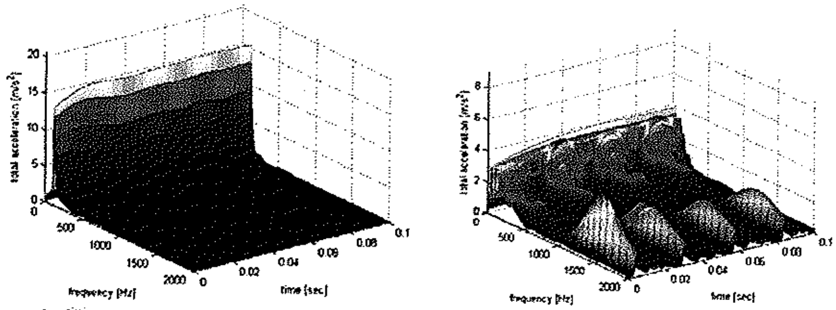


Figure 1: T-F characteristics of a concrete saw (left) and a riveting hammer (right).

Figure 2 compares the frequency-weighted and un-weighted 1/3 octave band spectra of the tools used in Figure 1. The spectra, especially in weighted forms, are not as strikingly different as those in Figure 1.

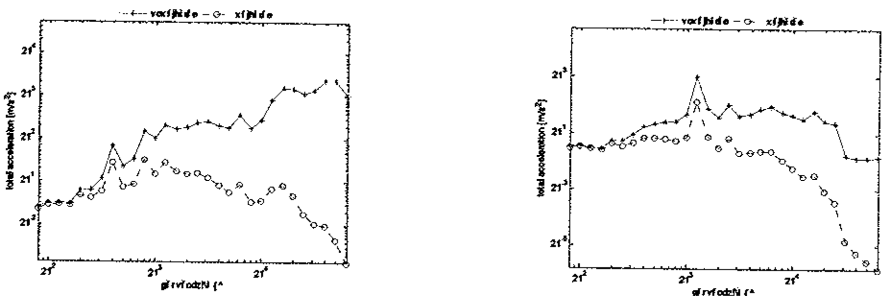


Figure 2: 1/3 octave band spectra of a concrete saw (left) and a riveting hammer (right).

Discussion

The frequency-weighted spectrum such as shown in Fig. 2 is used as the basis to calculate the vibration exposure dose in the standardized method.[1] The time averaging effect evens out the effect of sharp peaks that can be observed in Fig. 1. The health effects or thresholds of vibration exposure may be non-linear with respect to vibration magnitude, which may not be fully taken into account by the standard time-averaging- based method. The time-frequency-weighted acceleration can be calculated from the T-F spectra shown in Figure 1. Because the temporal changes of the frequency components can also be taken into account, the T-F method is believed to be a better approach than the conventional method for assessing the risk of impact vibration exposure.

References

1. ISO 5349-1, 2001: Mechanical vibration - measurement and evaluation of human exposure to hand-transmitted vibration - part 1: General requirements. Geneva, Switzerland: International Organization for Standardization.
2. Griffin, M., Bovenzi, M., Nelson, C.M., 2003. Dose-response patterns for vibration-induced white finger. Occup Environ Med 60:16-26.
3. Kulkarni, P., Zhu, X., Kim, J. and Hayden, C., 2004 Proceedings of NOISECON 2004, Baltimore, MD. 306-312 Time-frequency characteristics of high-intensity, fast transient noise from power tools by analytic wavelet transform.
4. ISO 8662-2, 1992: Hand-held portable power tools - Measurement of vibrations at the handle - part 2: Chipping hammer and riveting hammers. Geneva, Switzerland: International Organization for Standardization.

VARIATION IN THE VIBRATION EMISSION OF ROTARY HAMMER DRILLS UNDER SIMULATED WORK-SITE CONDITIONS

Neil J Mansfield
Environmental Ergonomics Research Centre, Loughborough University, Loughborough, U.K.

Introduction

Tool manufacturers are required to provide declarations of vibration emission values in order to sell their tools within Europe. To ensure that users can compare results obtained from different manufacturers, the declared values must be obtained using a methodology as specified in the relevant test code (such as in the ISO 8662 series of standards). In most cases, the vibration emission values obtained using test codes under-estimate the vibration that an operator will be exposed to when using the tool on a work-site. A further problem with manufacturers' data is that usually only a single value is provided for a tool. This is despite many factors affecting the vibration emission, including inserted tool type, work piece, operator technique, tool condition. New improved test codes are in the process of being developed.

In order to provide guidance to users on how to interpret manufacturers' data, a Draft CEN Technical Report (Draft CEN/TR 15350 (2005)) was developed. Part of the CEN/TR provides multiplication factors for combinations of task and tool type. For example, data obtained from electrical hammer drills (tested according to EN 60745-2-6:2003) should be multiplied by 2, for hammering applications, in order to obtain an estimate of the vibration emission during work.

In response to concerns from industry, the UK trade association OPERC have, in collaboration with hire companies and tool manufacturers, established a freely accessible online database of tool emission values based on independent tests carried out under simulated work-site conditions. This paper reports some of the data obtained from electrical hammer drills, highlighting the range of emission values that can be obtained for a tool. Data from many other tool types are also included in the database.

Methods

Tri-axial hand-arm vibration was measured at both handles of each of 19 electrical hammer drills, in accordance with ISO 5349-1 (2001). Each tool was measured with three experienced operators and at least 5 runs were completed for each operator. Tools were tested using a range of appropriate new bits from 4 to 40 mm diameter. The minimum number of bits for a tool was 3; the maximum number was 29. 146 tool / bit combinations are reported here, representing about 2200 individual 6-axis measurements. Operators were required to drill vertically into a concrete block with a compressive strength after 28 days of 40 N/mm^2. Two drills (1 and 15) were battery powered; others were powered using a 110V transformer supply.

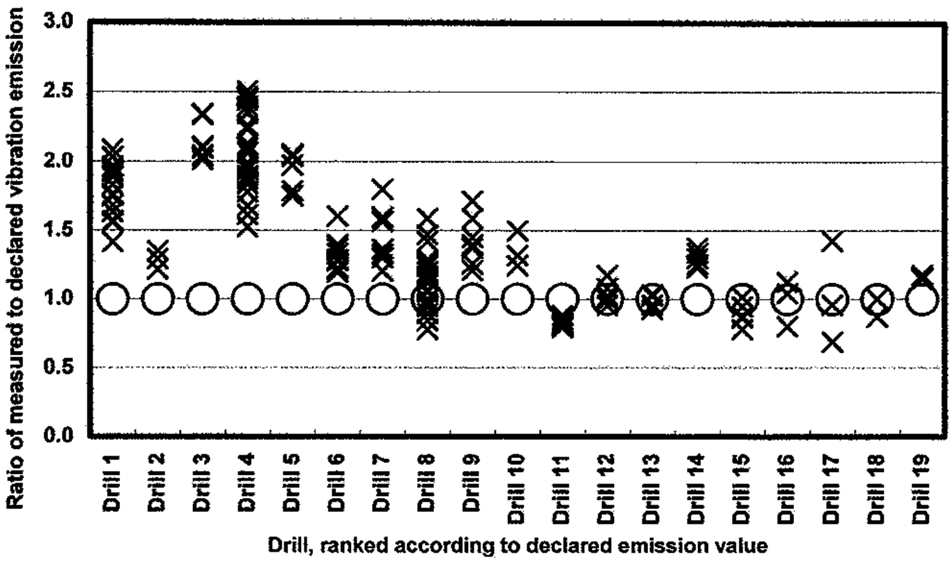


Fig 1. Ratio of measured emission to declared emission for 19 tools.

Results and Discussion

The relationship between the measured vibration and the declared vibration is illustrated in Fig 1. For those tools declaring vibration emission values less than 10 m/s^2 (Drills 1-10), work-site data were generally greater than declared values; for those tools declaring vibration emission values greater than 10 m/s^2 (Drills 11-19), work-site data were generally similar to declared values. Thus, if the scaling factors are used, those tools reporting higher but closer to simulated work-site values would be penalized.

In agreement with individual tool trends, there was a positive correlation between vibration emission and drill diameter (Fig 2, $p < 0.01$, Pearson). This indicates that provision of specific tool / bit data should improve applicability of risk assessments.

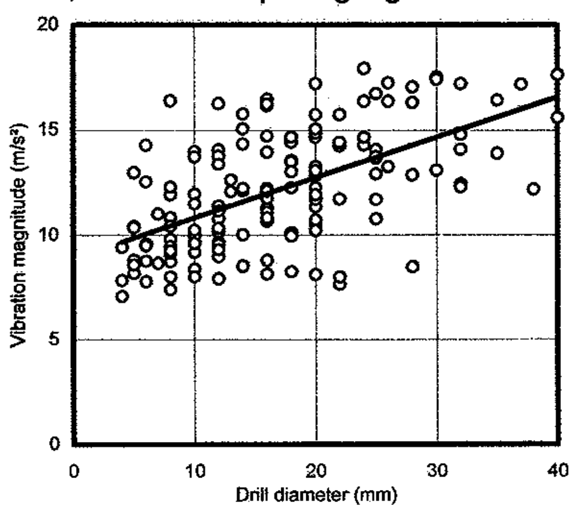


Fig 2. Relationship between drill diameter and vibration magnitude

Acknowledgements

Data in this abstract were drawn from the HAVTEC database (www.operc.com). The contributions of Dr David Edwards and Dr Andrew Rimell are acknowledged.

Reference

Draft CEN/TR 15350 (2005), Mechanical vibration – Guideline for the assessment of exposure to hand-transmitted vibration using available information including that provided by manufacturers of machinery.

DEVICE FOR MEASURING DAYLONG VIBRATION EXPOSURE AND GRIP FORCE LEVELS FOR DURING HAND-TOOL USE

D. R. Peterson, A.J. Brammer, M.G. Cherniack
Biodynamics Laboratory, University of Connecticut Health Center, U.S.A.

Introduction

Over the past two decades, there have been significant reductions in industrial exposures to hand-arm vibration, especially when specific tools and work processes have been redesigned to incorporate anti-vibration and ergonomic principles. Nevertheless, Hand-Arm Vibration Syndrome (HAVS) remains a significant occupational health problem as disease symptoms continue to occur even when vibration exposure levels believed to incur low risks have been reached[2]. This inconsistency may be related to the methodology that is typically used to estimate workday vibration exposure levels, involving laboratory and/or very short duration field measurements coupled with estimates of overall eight-hour tool operation times determined from brief observations of tool tasks and/or self-reported surveys. One solution is to use small, commercially-available, personal vibration dosimeters to calculate, record, and display long-duration vector sums and energy equivalents of vibration. However, since these devices are attached to the worker and require tool-mounted accelerometers, they are incompatible with the worker performing normal duties involving putting down or changing tools. In addition, these commercial systems do not allow for the characterization of the transmission of vibration to the hand such as monitoring the mechanical coupling between the hand and the tool handle (e.g., grip forces). O'Boyle and Griffin showed that variations in applied force can alter vibration transmission characteristics by 50% or more indicating that the measurement of grip force is essential for modeling vibration transmissibility and vibration exposures[5]. In summary, a need exists for the development of a method and device that will more accurately characterize workday-long vibration exposures.

Methods

A portable, light-weight, Vibration Exposure Monitor (VEM) system was developed to record user-specific tool-operating times, vibrations, and grip forces throughout all, or a representative part, of a workday. It monitors frequency weighted and unweighted accelerations from a palm-mounted uni-axial accelerometer (Model 352C22, PCB Piezotronics, Depew, NY) and calculates exposure levels using the root-mean-square (RMS) and higher power mean values, such as the root-mean-quad (RMQ) and the root-mean-oct (RMO). Grip forces are also monitored using a palm-mounted force sensor (Model 400, Interlink Electronics, Camarillo, CA) from which average grip force levels and exerted grip extrema are calculated.

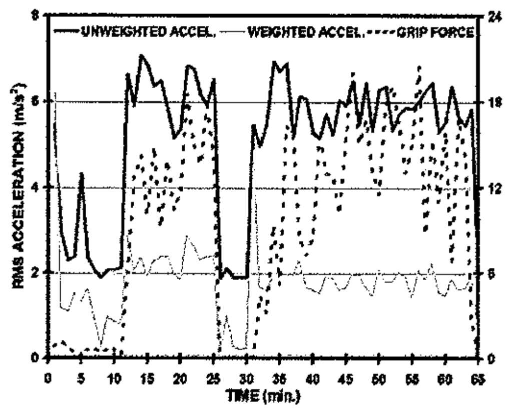
At the core of the VEM system is a commercially available, battery-powered microcomputer (Tattletale, Model 8v2, Onset Computer, Onset, MA) with one megabyte of memory and eight analog channels using 12-bit sampling at a single-channel maximum of 100 kHz. Analog signal processing (i.e., anti-aliasing, with cutoffs at 4 and 1250 Hz, and ISO 5349-1[3] frequency weighting) is accomplished using custom circuitry that is directly interfaced with the microcomputer. An embedded C-based protocol governs the data collection from each channel

at a 3 kHz sampling frequency and performs all vibration and grip force calculations. The entire VEM system, including the ICP-type accelerometer, is powered using three 9 V batteries and can provide measurements for up to 12 hours, while retaining data in the RAM for up to 72 hours.

Results

Measures of acceleration and grip were validated through laboratory studies involving an electro-dynamic shaker outfitted with a handle and actual power tools. The frequency response of the palm-mounted sensors was measured at a 100 N grip and showed a flat response up to 3 kHz. Results for weighted and unweighted vibration and grip force are presented in Fig. 1 for a 65-minute window of debrushing operations during forestry work.

FIG. 1: DEBRUSHING VIBRATION EXPOSURE



Discussion

Given the nature of the root-mean and averaged calculations, the measurements made using the VEM system only provide estimates of the time histories of accelerations entering the hands and for the grip forces exerted throughout the workday. These estimates have been seen to be more accurate than traditional methods and can be used to assist in the subsequent construction of vibration exposure metrics for the development of exposure-response relationships as described in ISO 5439-2[4] and more complex metrics involving biologically plausible models of tissue burden and dose[1]. These metrics may also assist in determining why deviations from ISO's energy-based exposure-response models occur.

References

1. Brammer, AJ, Peterson, DR, Cherniack, MG. (2001). Characterizing Exposure to Hand-Transmitted Impacts. Intl. Cong. of Occ. Health, Gothenburg, Sweden

2. Burström L, Hagberg M, Lundström R, Nilsson T. (2004). Relation Between Hand-arm Vibration Exposure And Symptoms Among Workers Within a Heavy-Engineering Production Workshop. 10th Intl. Conf. on Hand-Arm Vib., Las Vegas

3. ISO 5349-1 (2001). Mechanical vibration – Measurement and assessment of human exposure to hand-transmitted vibration – Part 1: General guidelines. ISO, Geneva, Switzerland.

4. ISO 5349-2 (2001). Mechanical vibration -- Measurement and evaluation of human exposure to hand-transmitted vibration -- Part 2: Practical guidance for measurement at the workplace. ISO, Geneva, Switzerland.

5. O'Boyle MJ, Griffin MJ. (2004). Transmissibility and Dynamic Stiffness of Glove Materials and the Apparent Mass of the Hand. 10th Intl. Conf. on Hand-Arm Vib., Las Vegas

CHALLENGES AND UNCERTAINTIES IN DESIGNING FIELD STUDIES TO MEASURE HAND VIBRATION

Dale AM, Standeven J, Evanoff B
Washington University School of Medicine, St. Louis, Missouri, U.S.A.

Introduction

We encountered several areas of methodologic uncertainty during development of a data collection method for use with vibrating hand tools in metal assembly. A local manufacturer sought our assistance designing a data collection method for evaluating and predicting risks of upper extremity disorders associated with use of vibrating hand tools. Current methods of vibration measurement are described in ISO 5349 [2]. However, the complexity of measuring vibration along with other exposures such as force and posture has limited the number of workplace-based studies of upper extremity disorders that have included direct measurements of vibration. Data from this preliminary study was used to look at two issues: a comparison of vibration values between production and non-production workers when performing the same task, and a comparison of worker ratings of vibration comfort to direct measurement of tool vibration.

Methods

Eight experienced production workers used each of six metal fastening tools to install fasteners. Vibration was collected by 3 tri-axial accelerometers, one attached to the tool handle following ISO 5349 recommended locations, one attached to the hand dorsum on the 3rd knuckle and one to the thumb side of the wrist. Data sampling rate was 10,000 samples/second. Hand grip and feed forces were obtained using a Novel pressure sensing mat on the palm. Each trial consisted of installing 10 fasteners per tool for each of the 6 tools. The test set-up placed the wrist in the position typically used by the operator during production. Each worker documented subjective comfort and effort ratings on a seven point scale following each series of fastener installations. One series of testing was completed by three non-production workers inexperienced in fastener installation to simulate use of alternative employees for data gathering. Vibration data for each trial were acquired, digitized, and stored using LabView. The X, Y, & Z axes were used to calculate the vector sum response for each tri-axial accelerometer. The tool data were digitally filtered following ISO recommendations. Calculated data consisted of the mean RMS over the tool's on- time, the starting and breaking peak impulses, and the peak of the frequency response.

Results

Production workers (n=8) were right hand dominant males with a mean age of 55 years and normal hand strength (mean right grip = 106 lbs). Non-production workers (n=3) had similar characteristics.

We found large and statistically meaningful differences in hand force during tool use between production and non-production workers (mean production workers = 9.77 lbs, mean non-production workers = 43.30 lbs, p = 0.0001). Vibration values obtained from the hand also showed a statistically meaningful difference (mean in production workers = 0.67 Gs, mean in non-production workers = 1.48Gs, p = 0.0014, figure 1). Experienced worker ratings of comfort during tool use demonstrated a moderate correlation with measured vibration (r=0.63). Worker ratings trended with direct recordings from the tool handle as shown in figure 2.

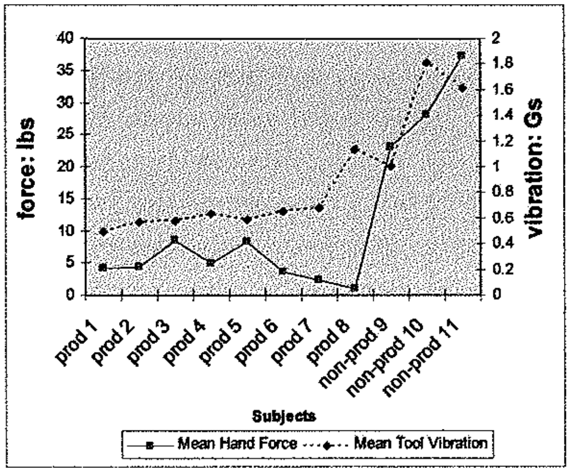


Figure 1. Comparison of hand force and vibration in production and non-production workers.

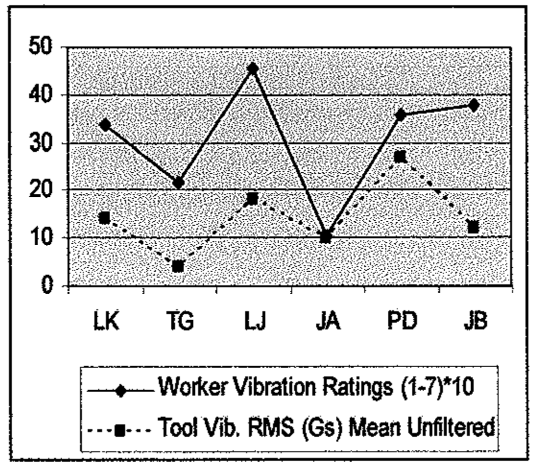


Figure 2. Comparison of worker ratings to vibration values produced for six different tools.

Discussion

This study highlights some of the issues that should be considered during vibration field studies. The striking differences in hand force and vibration between production and non-production workers suggest that vibration measures should be performed in the worker population actually using the tools. As workers become more adept at operating tools, they may use less hand force to perform a task, thus affecting vibration values. In our study, workers who were not experienced with daily use of the tools used higher hand force resulting in unreliable vibration values. The conditions of the field study should mimic real work conditions as much as is feasible, and deviations from normal work conditions should be considered when interpreting study results.

Our results also showed that worker ratings of tool vibration had reasonable correlation to measured vibration [1, 3]. This indicates that at least in a qualitative sense, experienced workers can estimate the magnitude of the vibration incurred during tool operation of familiar tools. Field studies may use worker rating data to identify problems or document the effectiveness of interventions. These data may supplement direct measures, particularly in large cohorts where direct measures on all subjects are impractical. Development of methods to estimate vibration under realistic work conditions will greatly enhance our ability to better understand the relationship between vibration and upper extremity disorders.

References

1. Annett, J, 2002, Subjective rating scales: science or art? Ergonomics, 45(14), 966-987.
2. International Organization for Standardization (ISO). Mechanical and evaluation of human exposure to hand transmitted vibration. Geneva 2001. ISO 5349-1 and 5349-2.
3. Latko, W.A., Armstrong, T.J., Foulke, J.A., Herrin G.D., Ranbourn, R.A., and Ulin, S.S., 1997, Development and evaluation of an observation method for assessing repetition in hand tasks. American Industrial Hygiene Association Journal, 58, pp. 278-285.

Podium Presentations

Session II: Health Effects I

Chairs: Suzanne Smith and Oliver Wirth

SJEF!N PUJPO!FGGFDUT!PO!UI F!BDDVSBDZ!PGSBQJE!QPJOUJOH!UBTL T

Kevin A. Rider, Bernard J. Martin
University of Michigan, Ann Arbor, Michigan, U.S.A.

Introduction

Reaching movements are planned and subsequently executed [1] using visual and somatosensory feedbacks [2], where absence of visual feedback is known to increase endpoint variability [3]. Visual occlusion decreases the ability to make rapid online compensatory movements, which results in initial radial deviations that are highly correlated with radial dispersion at the target. Perturbations of rapid, visually-guided reaches are compensated on-line and result in endpoint dispersions poorly correlated with initial deviations, emphasizing the strong effect of visual feedback in temporally-constrained reaching tasks. In control conditions (no vibration), these uncompensated, rapid reaches serve as estimates of the individual's intended trajectory. When ride motion is present, trajectories of rapid, visually-occluded reaches provide a measure of the natural biodynamic response of the cantilevered spine-arm-hand linkage. These intended movement trajectories and the biodynamic response (vibration feedthrough) are used to predict the effect of ride motion on the performance of rapid reaching tasks. Goals of this study are to investigate the influences of vehicle motion on human reaching and pointing, and to reveal movement strategies used in visually-occluded reaching tasks.

Methods

A six degree of freedom human-rated Ride Motion Simulator (RMS) was used to generate a dynamic vehicle environment. Participants performed discrete, rapid pointing tasks to targets presented on three touchpanel displays under stationary and random whole-body vibration. Reach instructions included ***successfully*** reaching identical circular targets (Ø = 0.25") with the right index fingertip ***as fast as possible***. Targets were presented on resistive-touch displays mounted approximately 60 cm from the participant's nasion. The touchpanel displays were located in the forward and lateral directions at eye level, and forward at 45° of elevation. These displays measured the spatial error of the reach destination. A ten-camera VICON motion capture system recorded the upper body kinematics of the participant. Reflective markers were placed on the participant's torso, head, and arms. Initial kinematics of the fingertip (i.e. time and magnitude peak tangential velocity) and tangential velocity at target were used to estimate the planned endpoint of the reach.

Results and Discussion

Ride motion resulted in increased endpoint variability compared to reaches performed in the stationary condition. Reaches to the elevated touchpanel consistently resulted in the largest variability across all motion conditions, suggesting that a vehicle occupant would not be capable of accurately activating a control in that location. Principal axes of endpoint ellipses were along and perpendicular to the direction of fingertip movements. Example graphs of endpoint variability with ellipses containing 95% of the data points are shown in Figure 1. These ellipses

might be used to enhance vehicle cockpit designs, where controls and displays could be shaped and oriented within the vehicle with respect to the operator and the probable reach direction.

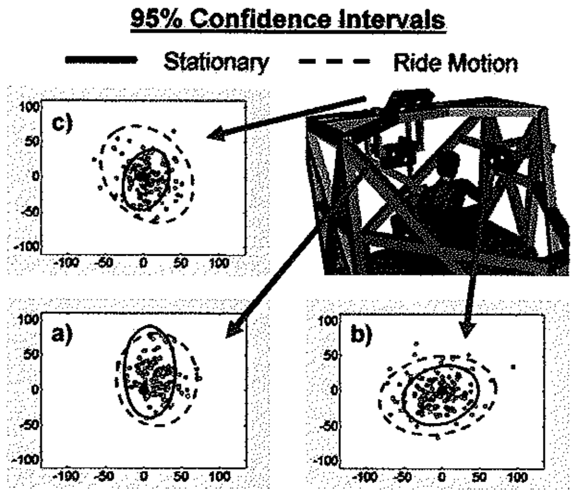


Figure 1. Comparison of 95% confidence ellipses of endpoint variability due to ride motion.

Analysis of the endpoint accuracy is illustrated using the circular representation in Figure 2a, where the deviations at peak velocity (PV, Figure 2b) are correlated with the deviations at the target (Figure 2c) with respect to the mean trajectory. If visual feedback mechanisms are not being utilized, than the dispersion of fingertip positions at PV (Figure 2b) should be replicated at the target. However, figure 2c shows that the actual endpoint dispersion at the target are poorly correlated ($R^2 = 0.07$) to values at PV for visually-occluded reaches, suggesting the interaction of proprioceptive feedback control.

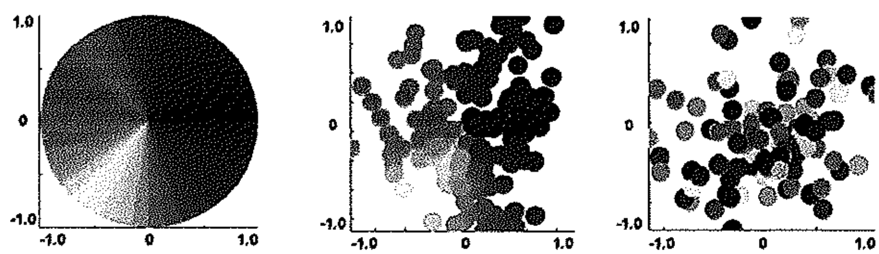


Figure 2. a) Illustration of the radial deviation of fingertip position at peak velocity (b, relative to the mean path) and reach endpoints (c, relative to the target center).

References

Bernstein N (1967) In: The coordination and regulation of movements. Oxford, New York: Pergamon Press.

Van Beers R, Sittig A, van der Goin J (1996) "Localization of a seen finger is based exclusively on proprioception and visual position information," Exp Brain Res 111: 253-261.

Keele S, Posner M (1968) "Processing of visual feedback in rapid movements," J Exp Psych 77: 155-158.

THE EFFECTS OF VIBRATION ON PSYCHOPHYSICAL GRIP AND PUSH FORCE-RECALL ACCURACY

TW McDowell[1], SF Wiker[2], RG Dong[1], DE Welcome[1]
[1]National Institute for Occupational Safety and Health, Morgantown, West Virginia, U.S.A.
[2]West Virginia University, Morgantown, West Virginia, U.S.A.

Introduction

Workers using vibrating hand tools have the potential for developing health problems associated with repeated forceful actions and exposures to hand-transmitted vibration. Hand-arm vibration syndrome (HAVS) and other hand-arm system disorders have been associated with such exposures.[1-2] To better assess health risks, comprehensive evaluations of these exposures must include quantitative assessments of hand-tool coupling forces; unfortunately, no standardized method for quantifying hand forces exists. Handle instrumentation may be ill-suited for some field environments. Psychophysical force-recall techniques may provide alternatives to handle instrumentation. A thorough understanding of the effects of vibration and other factors on force-recall accuracy and reliability is important before such methods are applied in risk assessments.

Methods

In this study, the effects of vibration and other factors on the accuracy of psychophysical force-recall were explored in two experiments. Twelve male subjects participated in the first experiment. The second experiment employed 20 participants (10 female, 10 male). In each experiment, participants applied specific grip and push forces to an instrumented handle mounted on a shaker system. Participants were exposed to sinusoidal vibration at frequencies that ranged from 0 Hz to 250 Hz. Three levels of applied force (low: grip = 15 N/push = 25 N, medium: grip = 30 N/push = 50 N, and high: grip = 45 N/push = 75 N) and two levels of vibration magnitude (low: ANSI 4-8-hr limit and high: ANSI <0.5-hr limit)[3] were examined. During the vibration exposure period, participants were provided with visual feedback while they attempted to "memorize" the applied grip and push forces. At the conclusion of the vibration exposure/force memorization period and a controlled rest period, the participants tried to duplicate the grip and push forces on a non-vibrating handle without the aid of visual feedback. The effects of different vibration frequencies, vibration magnitudes, and grip and push force levels were tested in a random order from trial to trial.

Results

Participants tended to overestimate grip and push forces. Depending on exposure conditions, error means ranged from 2 N to 10 N. The ANOVA revealed that force-recall errors for exposures between 31.5 Hz and 63 Hz were significantly higher than those at other vibration frequencies ($p < 0.05$). The frequency effect is depicted in Figure 1. Error means were greater when participants were exposed to the higher vibration magnitude (mean = 9.1 N, 95% CI = 8.2-10.1 N) when compared with the lower vibration magnitude (mean = 4.9 N, 95% CI = 3.9-5.8 N) ($p < 0.05$). The effect of vibration magnitude is shown in Figure 2. The average error for

females (4.9 N, 95% CI = 4.0-5.8 N) was significantly less than that for males (8.3 N, 95% CI = 7.4-9.2 N) ($p < 0.05$). The effects of force level were mixed.

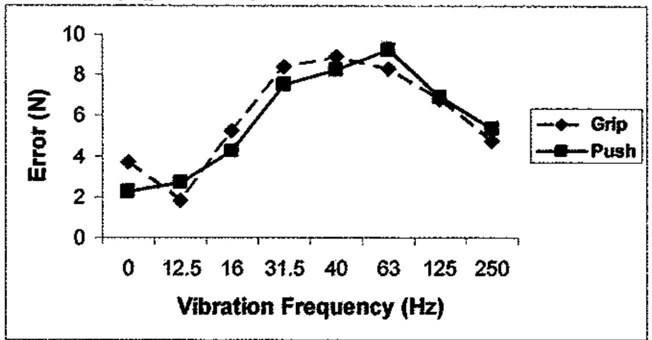


Figure 1. Grip and push force-recall error means plotted vibration frequency across all conditions of the two experiments.

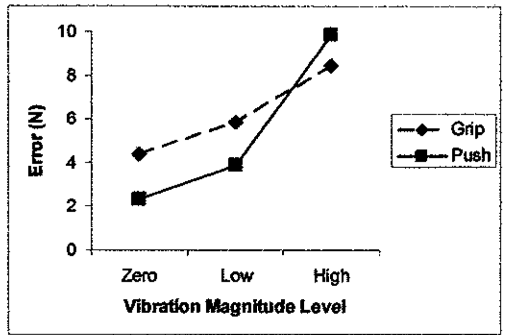


Figure 2. Force-recall error as a function of against vibration magnitude (Low = ANSI 4-8 -hr limit, High = ANSI <0.5-hr limit)[3] and exertion type.

Discussion

Overall, recalled force errors were relatively small over the range of operationally-relevant hand-handle coupling forces and vibration exposure conditions. Vibration exposure significantly affected grip and push force-recall accuracy. This result is consistent with previous research.[4-5] The vibration effect was particularly pronounced with vibration exposures between 31.5 Hz and 63 Hz. This frequency range coincides with that of hand-arm system resonance.[6-7] The effect of vibration was greater at higher levels of vibration magnitude. This force-recall technique shows promise as an alternative to expensive and fragile force-sensing instrumentation. For example, to account for anticipated force-recall errors due to vibration effects, weighting functions can be developed to yield accurate force estimates. Once refined, this psychophysical force-measuring technique can be incorporated into various risk assessments of hand-transmitted vibration.

References

1. Griffin, M.J. and Bovenzi, M. (2001). The diagnosis of disorders caused by hand-transmitted vibration: Southampton workshop 2000. Int Arch Occup Environ Health. 75, 1-5.
2. NIOSH. (1997). Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back, NIOSH publication 97-141. U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health, Cincinnati, OH.
3. ANSI. (2002). ANSI S3.34, 2002: Guide for the measurement and evaluation of human exposure to vibration transmitted to the hand. American National Standards Institute (ANSI), New York.
4. Nowak, D.A., Rosenkranz, K., Hermsdorfer, J. and Rothwell, J. (2004). Memory for fingertip forces: Passive hand muscle vibration interferes with predictive grip force scaling. Exp Brain Res. 156, 444-450.
5. Cafarelli, E. and Kostka, C.E. (1981). Effect of vibration on static force sensation in man. Exp Neurol. 74, 331-340.
6. Kihlberg, S. (1995). Biodynamic response of the hand-arm system to vibration from an impact hammer and a grinder. Int J Ind Ergo. 16, 1-8.
7. Dong, R.G., Schopper, A.W., McDowell, T.W., Welcome, D.E., Wu, J.Z., Smutz, W.P., Warren, C. and Rakheja, S. (2004). Vibration energy absorption (VEA) in human fingers-hand-arm system. Med Eng Phys. 26, 483-492.

COMFORT EVALUATION FOR MINE SHUTTLE CAR SEAT DESIGNS

Alan Mayton[1], Christopher Jobes[1], N. Kumar Kittusamy[2], Farid Amirouche[3]
[1]NIOSH, Pittsburgh Research Laboratory, Pittsburgh, Pennsylvania, U.S.A.
[2]NIOSH, Spokane Research Laboratory, Spokane, Washington, U.S.A.
[3]Vehicle Technology Laboratory, University of Illinois at Chicago, Illinois, U.S.A.

Introduction

Industrial equipment exposes individuals to whole-body vibration (WBV) and mechanical shock. This exposure can negatively impact their health, safety, comfort, and working efficiency and performance. Accordingly, proper seat design is an important consideration in reducing the adverse effects of WBV exposure to vehicle operators. Since the human body is sensitive to low frequency WBV, ride quality is a basic and important element of good seat design. When designing a suitable seat, it is essential to understand vibration exposure environment of workers and how well they can tolerate this environment [1]. This is particularly true in the mining industry.

Mayton et al. [2] reported on a low-coal shuttle car seat design that underwent limited, yet successful underground mine trials. Building on this work, a follow-up study compared NIOSH and existing seat designs on low- and mid-coal seam shuttle cars. The NIOSH seat designs included viscoelastic foam, which has properties similar to those found in a mechanical spring/damper suspension system. The seats also included an adjustable lumbar support and a fore-aft seat adjustment. The NIOSH seat designs contrast with the existing seat design, which have little or no lumbar support and include inexpensive foam padding of the type commonly used in furniture.

This paper will focus on the seat designs for the mid-coal seam shuttle car and compare subjective comfort data collected from five vehicle operators with ISO 2631 – based reduced comfort boundary (RCB) analysis of recorded vibration levels.

Methods

Experimental data were collected using three different tools: triaxial accelerometers, pre-amplifiers, and filters connected to a data recorder; a visual analog scale (VAS); and a short questionnaire.

Researchers recorded quantitative or objective vehicle vibration data to determine the input and output acceleration at the operator cab floor and operator seat interface. Qualitative or subjective data, collected with the VAS, allowed researchers to obtain the operators' immediate impressions of shock, vibration, and discomfort levels for the vehicle ride on each of the seat designs. Each shuttle car operator made six round trips with the vehicle each seat. The shuttle car operator marked the VAS on the first, third, and sixth round trip of the trials for each seat. A round trip consisted of traveling to the coal face with no load and returning to the load discharge location with a full load of coal.

Results

Total overall average ratings for the five vehicle operators of the mid-coal seam shuttle car, showed that operators sensed from 45 to 87% <u>less</u> discomfort with NIOSH seat designs compared to the existing seat design. Using a 95% CI, researchers computed a strong positive correlation for discomfort.

Figure 1 illustrates the RCB analysis method for one of two NIOSH seat designs.

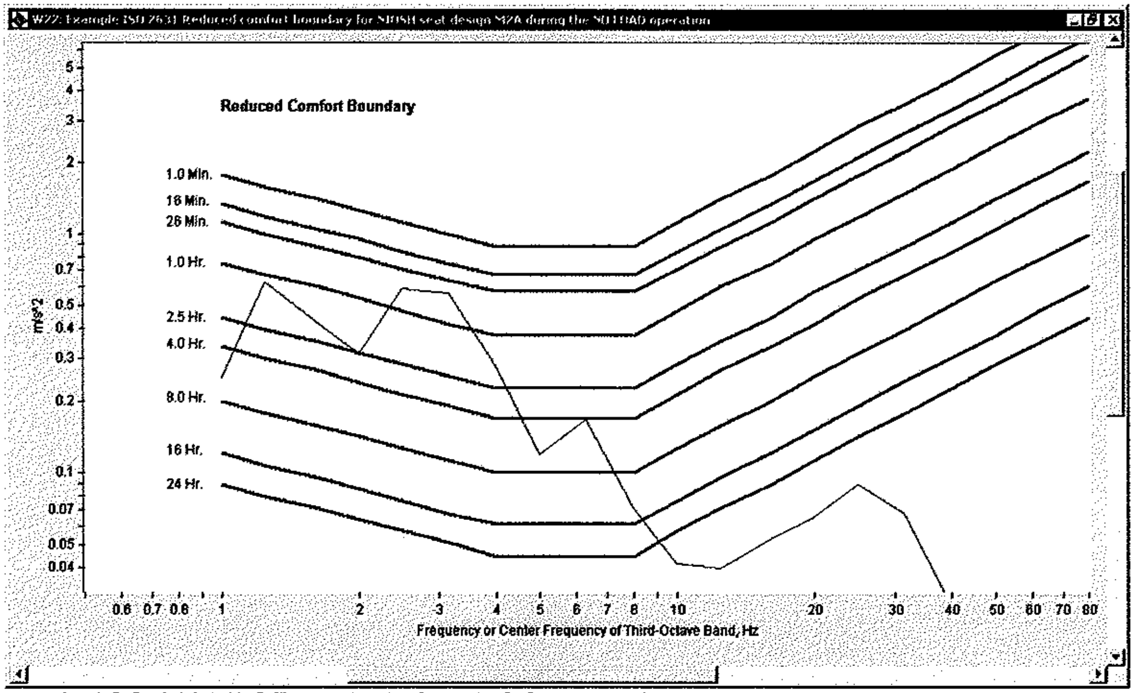


Figure 1. ISO 2631 RCB analysis for NIOSH seat design during *no load* operation.

Discussion

The RCB analysis during no-load operation showed that NIOSH seat designs, compared to the existing seat design, generally provided an increase in allowable exposure time for the vehicle operator, in the 4 to 8 Hz range. During full-load operation, the RCB analysis showed little difference in allowable exposure time for either the NIOSH or the existing seat designs. The natural frequency of the vehicle decreases for full-load operation as shown by the equation, $\omega = \sqrt{k/m}$ where, ω is the natural frequency, k is the spring constant, and m is the mass. Foam- or air-filled tires provide primary damping or attenuation of jars/jolts when the vehicle mass is increased with the full load of coal. Seat performance in attenuating of jars/jolts is thus secondary. The RCB acceleration-based analysis appears inadequate for correlating operator perceptions of discomfort. Vehicle operators' perceptions of discomfort are based more on the energy they sense transmitted to their bodies through the seat from the floor of the vehicle. So, the use of the absorbed power analysis reported by Mayton et al. [3], on the other hand, may provide a better means of correlating operator perceptions of vibration energy rather than the acceleration levels of the ISO 2631 RCB method.

References

1. Amirouche F., Xu P., and E. Alexa (1997). Evaluation of dynamic seat comfort and driver's fatigue. SAE 971573, 12 pp.
2. Mayton A., Merkel R., and S. Gallagher (1999). Improved seat reduces jarring/jolting for operators of low-coal shuttle cars. Min. Eng. vol. 51, no.12, pp. 52-56.
3. Mayton A., Amirouche F., and C. Jobes (2005). Comparison of seat designs for underground haulage vehicles using the absorbed power and ISO 2631-1 (1985)-based ACGIH threshold limits methods. Int. J. Heavy Vehicle Systems, vol. 12, no.3, pp. 225-238.

A METHOD OF EVALUATING VEHICLE SEAT VIBRATION WITH CONSIDERATION OF SUBJECTIVE JUDGMENT

Yumi Nakashima, ISUZU Advanced Engineering Center, Fujisawa, Japan
Setsuo Maeda, National Institute of Industrial Health, Kawasaki, Japan

Introduction

Vibration magnitude and frequency of the z-axis vehicle seat are time-variant, which are influenced by not only vehicle vibration characteristics themselves but also road surfaces, speeds and the human body. There is little in the current reporting about evaluating and analyzing automobile seat vibration that focuses on the time-variant.

Yaguchi et al.[1] has proposed a method to evaluate automobile seat vibration that is based on judgments using a subjective mental state. Their method focuses on the time-variant magnitude of the peak frequency on a power spectrum density. However, their method has no consideration of all the frequency contents of the discomfort, nor comparison between different peak frequency vibrations. Suzuki[2] has emphasized that the vehicle vibration should be judged by a series of vibration stimuli to evaluate, because the vehicle vibration is time-variant, which isn't a matter of the relationship between a single vibration stimulus and a subjective response. He clarified that the human sensation to the vehicle vibration discomfort changes every moment showing the relationship between the frequency-weighted r.m.s. acceleration calculated every 5 seconds and the category judgment to vehicle vibration discomfort every 5 seconds. However, his study doesn't show what parameter connects to the subjective final judgment to vehicle vibration.

Therefore, we applied the method similar to ISO10056[3] considering the time-variant to the vehicle seat z-axis vibration evaluation. The new method for the vehicle seat vibration considering the time-variant was examined on the hypothesis that the final subjective evaluation must be conducted from the judgment summarizing a series of vibration stimuli.

Methods

The vibration bench system, which reproduces the movement of a vehicle floor, was used for the experiment with the single-axis (vertical direction) four-post road simulator system, which is usually used for a car, as shown in Fig.1. The experiment was done on the right side of the vibration bench using the floor vibration which was 5.5 minutes, 0.822 m/sec^2 (Wk) over the range 0.5-20Hz with 4 male subjects (age ave21.5, SD0.5, weight ave75kg, SD7.91kg, height ave166.8cm, SD5.2cm) and 4 suspension seats. As Fig.2 shows, subjects evaluated the degree of discomfort every 5 seconds to each seat vibration measuring the seat z-axis vibration acceleration.

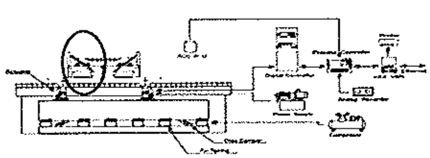


Fig1. Road simulator system

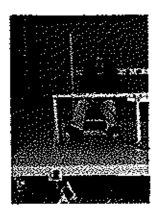


Fig 2. Right side of vibration bench system

Results

Fig.3 shows the discomfort evaluated every 5 seconds by 4 subjects matched up to frequency-weighted r.m.s. acceleration calculated every 5 seconds. Other seats also had the same tendency. As Table1 shows, evaluations by ISO2631-1[4] didn't fit final judgments by each subject. Table2 shows statistical parameters from cumulative distribution histogram of frequency-weighted r.m.s. acceleration calculated every 5 seconds applied the method of ISO10056. Seat A and Seat B had larger frequency weighted r.m.s. acceleration of the 90% band range than Seat C and Seat D. Seat A, which had the least discomfort, as judged by most of the subjects, had smaller values over all than Seat B had.

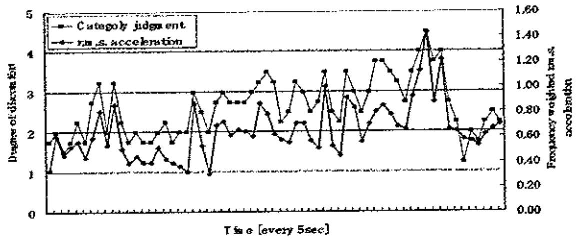


Fig.3 Seat A results of Frequency weighted r.m.s. accelerations and category judgments every 5 seconds.

Table 1. Evaluations by ISO2631-1 and subjective final judgments

	Seat A	Seat B	Seat C	Seat D	Least Discomfort seat
Subject1	0.694	0.675	0.665	0.65	Seat A
Subject2	0.673	0.728	0.647	0.66	–
Subject3	0.674	0.743	0.688	0.638	Seat A
Subject4	0.645	0.76	0.626	0.647	Seat A
Average	0.671	0.727	0.656	0.649	
SD	0.017	0.032	0.023	0.008	

Table 2. Statistical parameters of Wk r.m.s. acceleration cumulative distribution histgram

	Seat A	Seat B	Seat C	Seat D
Average	0.647	0.697	0.647	0.631
SD	0.216	0.244	0.166	0.191
Max	*1.456*	*1.552*	1.274	1.351
99%tile	*1.425*	*1.525*	1.225	1.325
95%tile	*1.045*	*1.17*	0.975	1
5%tile	*0.362*	*0.375*	0.416	0.375
1%tile	*0.287*	*0.3*	0.375	0.312
Min	*0.27*	*0.28*	0.36	0.294
80%band	*0.5*	*0.604*	0.416	0.45

Discussion

It was shown that the human sensation of discomfort to vehicle seat vibration changes every moment influenced by the time-variant seat vibration. It clarified the new evaluation and analysis method for seat vibration that was based on the hypothesis that the final judgment was conducted from summarizing a series of time-variant vibration stimuli. An additional study is required to investigate the applicability to different types of vehicle vibration using a larger number of subjects.

References

1. Yaguchi E, Yanagishima T, Akatsu Y, Hanai T and Kato K (1994) Whole-Body Vibration and Ride Comfort, Inter-noise94, 905-910
2. Hiroaki Suzuki (1997) A study on the vibrational factors determining the riding comfort of railway vehicle, The Japanese Journal of Ergonomics Vol33, NO.6, 349-355
3. International Organization for Standardization (2001) Mechanical vibration – Measurement and analysis of whole-body vibration to which passengers and crew are exposed in railway vehicles. ISO10056
4. International Organization for Standardization (1997) Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration Part1: General requirements. ISO2631-1.

PERCEPTION THRESHOLDS FOR LATERAL VIBRATION AT THE HAND, SEAT, AND FOOT

Miyuki Morioka and Michael J. Griffin
Human Factors Research Unit
Institute of Sound and Vibration Research, University of Southampton, Southhampton, U.K.

Introduction

Discomfort, annoyance, or interference with activities due to exposure to vibration is only expected if the vibration exceeds the threshold for the perception of vibration. When there is more than one vibration input to the body (e.g. at the hands, seat and feet), the sensation is first experienced at the location with greatest sensitivity. Knowledge of differences in the thresholds of perception for vibration at the hand, seat, and feet should assist the identification of sources of discomfort caused by vibration.

Perception thresholds for vibration have been determined in several studies, but only a few studies have investigated perception thresholds in the horizontal direction for hand-transmitted vibration [2-17] or whole-body vibration [5,6], and there has been little consideration of perception thresholds for the foot resting on a vibrating surface.

This study determines absolute thresholds for the perception of sinusoidal lateral vibration, examining the effect of vibration frequency (8 to 315 Hz for the hand and foot; 2 to 315 Hz for the seat) and the effect of input location (the hand, the seat and the foot).

Methods

Three groups of twelve males aged between 20 and 29 years participated in the experiment. Subjects in each group attended an experiment to determine perception thresholds for lateral vibration via either a rigid handlebar (30 mm diameter) at the left hand (left hand), or a rigid contoured seat (250 mm x 150 mm), or a footrest at the left foot (30.5 mm x 10.5 mm with 10-degree inclination). For the non-exposed hand (right hand) or foot (right foot), a stationary handle and footrest with the same dimensions as the vibrating handle and footrest were provided so that the same body posture was adopted among the three groups of subjects.

An up-down (staircase) algorithm was employed to determine thresholds in conjunction with a three-down one-up rule. A single test stimulus (2.0 seconds) was presented with a cue light illuminated during this period. The task of the subjects was to indicate whether they perceived the vibration stimulus or not. The threshold was calculated from the mean of the last two peaks and the last two troughs, omitting the first two reversals.

Results

The median absolute thresholds of the 12 subjects determined at each frequency for the hand, seat and foot are shown in Figure 1. A frequency dependence of the threshold contours within the investigated frequency range is evident, with similar shape to the threshold contours

determined in other research[4,7]. Among the three locations (hand, seat and foot), the thresholds between 25 and 63 Hz did not differ significantly. The seat was the most sensitive to lateral vibration at 8 and 10 Hz among the three locations (Mann-Whitney, $p<0.05$). The hand was less sensitive to lateral vibration than the seat and foot at 12.5, 16 and 20 Hz (Mann-Whitney, $p<0.05$), but more sensitive than the seat and foot at frequencies greater than 100 Hz (Mann-Whitney, $p<0.05$).

Discussion

It is evident from Figure 1 that the vibration threshold contours derived from the present study are inconsistent with the reciprocals of the relevant frequency weightings (e.g. W_h, W_b, and W_d) in current standards[2,3], indicating greater sensitivity at high frequencies relative to low frequencies than implied by the standards for predicting perception thresholds at the hand, the seat, and the foot.

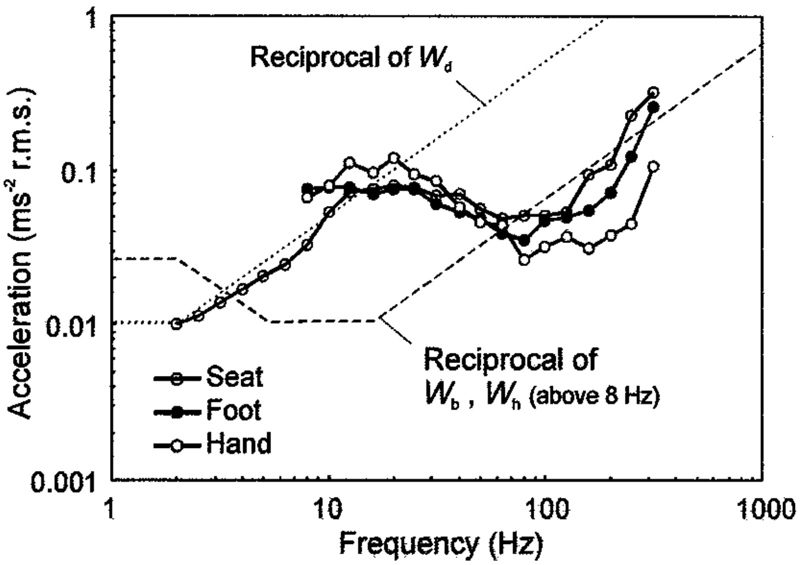


Figure 1 Median perception threshold contours for lateral vibration at the hand, seat and foot. The reciprocals of W_b, W_d, and W_h frequency weightings[2,3] normalized to 0.01 ms^{-2} r.m.s. are overlaid.

References

1. International Organization for Standardization (2001) Mechanical vibration – Measurement and assessment of human exposure to hand-transmitted vibration – Part 1: General guidelines, ISO 5349-1.

2. International Organization for Standardization (1997) Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General requirements, ISO 2631-1.

3. Miwa, T. (1967a) Evaluation methods for vibration effects. Part 3: Measurements of threshold and equal sensation contours on hand for vertical and horizontal sinusoidal vibrations, Industrial Health 5, 213-220.

4. Miwa, T. (1967b) Evaluation methods for vibration effect Part 1. Measurements of threshold and equal sensation contours of whole body for vertical and horizontal vibrations, Industrial Health, 2, 183-205.

5. Parsons, K.C., and Griffin, M.J. (1988) Whole-body vibration perception thresholds, Journal of Sound and Vibration, 121 (2) 237-258.

6. Reynolds, R.R., Standlee, K.G., and Angevine, E.N. (1977) Hand-arm vibration, Part III: Subjective response characteristics of individuals to hand-induced vibration, Journal of Sound and Vibration 51, 267-282.1.

NEUROMOTOR HABITUATION AS A MECHANISM FOR VIBRATION INDUCED LOW BACK PAIN

Sara E. Wilson and Lu Li
Mechanical Engineering, University of Kansas, Lawrence, Kansas, U.S.A.

Introduction

Occupational exposure to whole body vibration has long been associated with increased incidence of low back pain and low back injuries[1]. A number of studies have investigated transmissibility of seat pan vibration [5, 6]. While transmissibility has been well researched, the mechanism by which vibration may induce injury has not been thoroughly studied. Winter et al. identified increased reflex response delay after vibration exposure and speculated that muscular fatigue may be the cause of this increase[9]. However, a mechanism has yet to be demonstrated completely.

A potential mechanism that may explain the increased risk is neuromotor habituation. Muscle spindle organs have been shown in the extremities to be sensitive to muscle and tendon vibration. Rapid length changes in muscle have been shown to result in kinesthetic illusions as the regular firing of the muscle spindles is interpreted as muscle lengthening[4, 7]. These illusions have also been demonstrated in the paraspinal musculature[2]. With removal of vibration, research in the extremities has demonstrated increased positioning errors, probably due to neuromotor habituation[8].

In this research, it has been hypothesized that neuromotor habituation after exposure to occupational vibration will increase positioning errors. It is further hypothesized that these errors can be shown to be linked to increased reflex response time. Such increased reflex response time could, in turn, decrease spinal stability and increase low back injury risk.

Methods

Both positioning error and sudden load response were measured before and after exposure to 20 minutes of 5 Hz, 0.223 m/s^2 RMS seat pan vibration. Subjects were asked to sit on an unpadded seat without a backrest. Throughout the whole body vibration period, subjects were instructed to put their hands on a stable hand rest and feet on an adjustable stable footrest. The subjects were instructed to assume a comfortable and relax sitting posture for the duration of the exposure.

Positioning error was measured using an active-active reposition sense protocol. Electromagnetic markers (Motionstar, Ascension Tech, Burlington, VT) were used to track trunk motion. With markers attached to the skin at the T10 vertebra, the S1 vertebra and manubrium, trunk flexion (the angle from vertical of the line connecting T10 and S1) and lumbar curvature (the difference in inclination of the T10 and S1 markers) were tracked. In the reposition sense protocol, subjects were asked to maintain an upright trunk flexion and to rotate their pelvis and lumbar curvature to assume a target lumbar curvature. In the protocol subjects completed training trials, where they were asked to match their lumbar curvature using a visual display, and assessment trials, where they were asked to reproduce the lumbar curvature from memory. After two initial training trials, training trials and assessment trials were alternated for a total of 3 assessment trials. Reposition error was defined as the absolute difference between the target lumbar curvature and the lumbar curvature the subject assumed during the assessment trials.

For sudden loading trials, subjects were asked to stand on a force plate with their pelvis fixed with a belt. A sudden impulse load was applied by dropping a weight of 4.5 kg a height of 10 cm. The weight applied a sudden flexion moment through a chest harness. Electromyographic (Delsys, Boston, MA) data was recorded from the erector spinae, rectus abdominus and internal and external oblique muscle groups. Trunk motion was collected with the electromagnetic sensors.

A simulink model (MATLAB, Natick MA) was created in which the trunk was modeled as an inverted pendulum and muscle reflex response was modeled as a feedback with a detection threshold, a fixed time delay, and a linear gain. Overall trunk stiffness and trunk inertia from Cholewicki et al. were used[3]. An increase in positioning errors was modeled as an increase in detection threshold.

Results

Both reposition error and erector spinae muscle activity delay were found to increase significantly after exposure to vibration, returning close to baseline after approximately 20 minutes. This pattern was also reflected in the significant increase after vibration in trunk flexion in response to sudden loading.

By increasing detection threshold for reflex response in the model, it was possible to show that changes in the detection threshold (position error) would indeed increase response delays and increase trunk flexion. It was shown that altering gain did not change these delays suggesting that muscular fatigue may not explain the data.

Discussion

From the model, it can be predicted that loss in proprioception (position sense) can lead to increased muscle response times and increased trunk flexion in response to a sudden load. This was also demonstrated experimentally. This association supports the hypothesis that neuromotor habitation from vibration can lead to loss in proprioception and in turn alter low back stabilization. Future work will examine occupational factors such as seating configuration and vibration frequency on these neuromotor changes.

References

1. Bernard, B. P. (Ed.) (1997) Musculoskeletal disorders and workplace factors, Washington, D.C., U.S. Department of Health and Human Services.
2. Brumagne, S., Lysens, R., Swinnen, S. & Verschueren, S. (1999) Effect of paraspinal muscle vibration on position sense of the lumbosacral spine. Spine, 24, 1328-31.
3. Cholewicki, J., Simons, A. P. & Radebold, A. (2000) Effects of external trunk loads on lumbar spine stability. J Biomech, 33, 1377-1385.
4. Cordo, P., Gurfinkel, V. S., Bevan, L. & Kerr, G. K. (1995) Proprioceptive consequences of tendon vibration during movement. J Neurophysiol, 74, 1675-88.
5. Griffin, M. J. (1990) Handbook of human vibration, London, England, Academic Press Limited.
6. Pope, M. H., Magnusson, M. & Wilder, D. G. (1998) Kappa Delta Award. Low back pain and whole body vibration. Clin Orthop, 241-8.
7. Roll, J. P. & Vedel, J. P. (1982) Kinaesthetic role of muscle afferents in man, studied by tendon vibration and microneurography. Exp Brain Res, 47, 177-90.
8. Wierzbicka, M. M., Gilhodes, J. C. & Roll, J. P. (1998) Vibration-induced postural posteffects. J Neurophysiol, 79, 143-50.
9. Wilder, D. G., Aleksiev, A. R., Magnusson, M. L., Pope, M. H., Spratt, K. F. & Goel, V. K. (1996) Muscular response to sudden load. A tool to evaluate fatigue and rehabilitation. Spine, 21, 2628-39.

Podium Presentations

Session III: Biodynamics I

Chairs: Douglas Reynolds and Farid Amirouche

PNEUMATIC ACTIVE SUSPENSION DESIGN FOR HEAVY VEHICLE SEATS AND OPERATOR RIDE COMFORT

Bertrand Valero[1], Farid Amirouche[1], Alan Mayton[2]
[1]Vehicle Technology Laboratory, University of Illinois at Chicago, Illinois, U.S.A.
[2]NIOSH, Pittsburgh, Pennsylvania, U.S.A.

Introduction

Handling of heavy vehicles such as tractors, trucks and buses require a large roll stiffness which causes large high accelerations at the seat level during impacts. To provide comfort and minimize the energy transfer from the chassis and the seat a pneumatic active seat suspension is proposed. An active seat suspension design and control algorithm under development at the University of Illinois at Chicago, UIC, is being developed and tested. Preliminary results are presented in this paper.

The design of a passive suspension typically consists of optimizing the value of two parameters: the stiffness and the damping of the suspension. The general dynamic performance of the suspension is limited to the conditions under which these parameters were obtained. A change in the input conditions might lead to poor suspension and an amplification of the vibration transmitted to the body. The focus of this paper is a robust, semi-active suspension system with a variable controlled damping and using the body response an index measure to minimize the acceleration at the interface of the seat and operator.

A summary of existing suspensions, such as MR and ER fluids, and spring loaded and dual valve shock absorbent will be discussed to highlight the need of a semi-active pneumatic suspension system design.

Methods

A model of the proposed suspension was developed in MATLB (Simulink) and different control strategies for the valve position in relation to the cylinder pressure tested. The effects of stiffening and softening resulting from pressure changes in the cylinder were examined. The vertical accelerations of the seat was computed for different control strategies and configurations of the suspension and compared to the response of a passive seat suspension.

A lump -mass model was created to represent the human body including the head, the upper, middle and lower torso as well as the legs. The connective forces between body segments were modeled through modal analysis techniques from previous experiments at the Vehicle Technology Laboratory. ISO standards and absorbed power were used to evaluate the different configuration of the seat suspension system in relation to the dynamic response of the operator.

Results

Initial results of the semi-active suspension system show a significant reduction in the RMS value of the acceleration of the seat. A reduction of the total absorbed power by the operator is expected to provide an insight into the control strategies adapted in the active suspension.

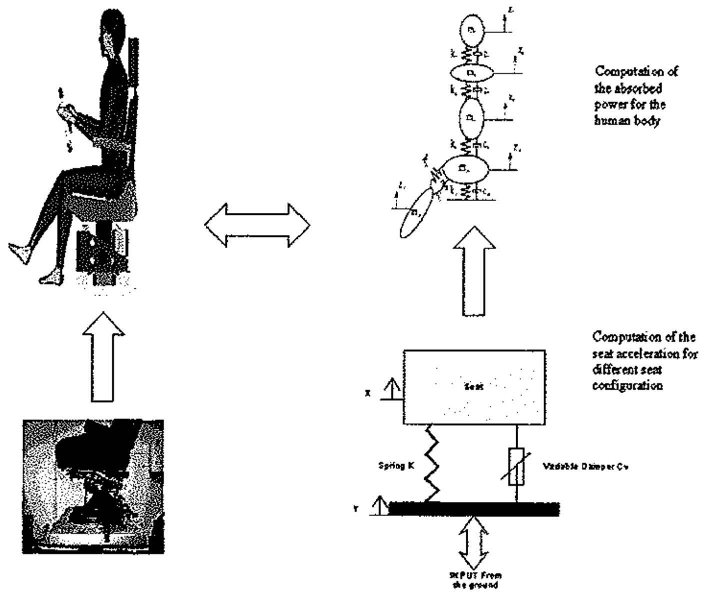


Figure 1 : Scheme of the general method applied in the study

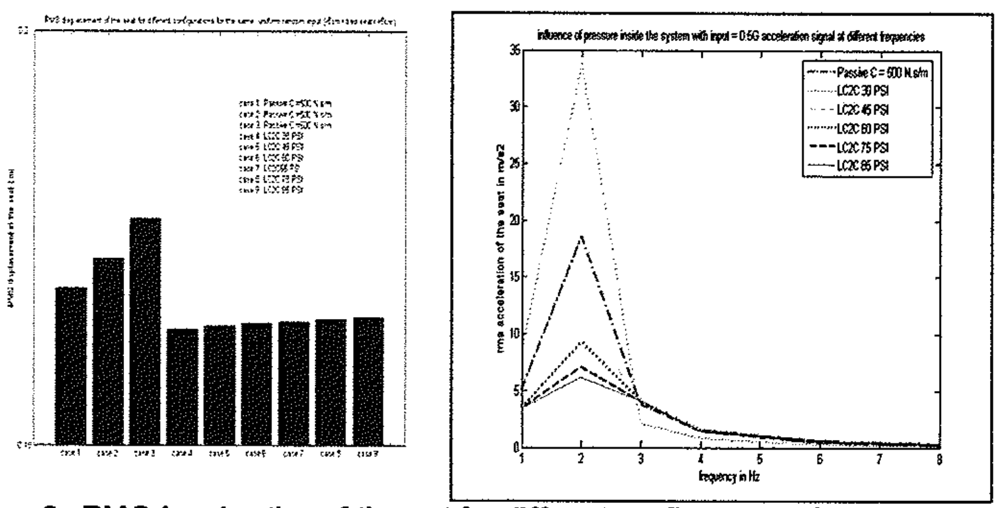


Figure 2 : RMS Acceleration of the seat for different configuration of the suspension

References

1. F.M.L. Amirouche, Computational Methods in Multibody Dynamics. Practice Hall,
2. F.M.L. Amirouche, Advanced Topics in Seat Suspension Design and Human Body Vibration Control. SAE Seminars, 1998
3. F.M.L. Amirouche, L. Palkovics and J. Woodrooffe, Optimal driver seat suspension design for heavy trucks, International Journal of Vehicle Design, 1992

HAND FORCE-DEPENDENT MODELING OF THE HAND-ARM UNDER Z_H-AXIS VIBRATION

Y. Aldien[1], S. Rakheja[1], P. Marcotte[2], P.-E. Boileau[2]
[1]CONCAVE Research Center, Concordia University, Montréal, Canada
[2]Institut de recherche Robert-Sauvé en santé et en sécurité du travail, Montréal, Canada

Introduction

A number of biodynamic models of the hand-arm system have evolved on the basis of measured driving-point mechanical impedance (DPMI) responses to facilitate analyses of the coupled hand-tool system [1]. The parameter identifications in such models are based upon minimization of an error function of the model and the target impedance data, which may not yield a unique solution. Consequently, a number of model structures and parameter sets could be realized that would equally satisfy the target curve. Moreover, the vast majority of the reported models exhibit acute deficiencies due to excessive static deflections of model masses, presence of a low frequency mode and very light masses in the order of 1.2- 4.8 grams. The models also do not characterize the dependency of the biodynamic responses on many factors, namely the hand forces, hand-arm posture and vibration intensity. This study aims at development of a hand-arm biodynamic model with considerations of the hand forces, and both the DPMI and power absorption measures, to enhance the uniqueness of the model.

Methods

Two different model structures are chosen for identifying the model parameters on the basis of measured DPMI and absorbed power characteristics of the hand-arm system under z_h-axis vibration over a range of hand-grip and push forces. Owing to the strong influence of the hand-handle coupling forces, the models were initially derived for fixed hand forces, namely 30 N grip and 50 N push forces, as suggested in the ISO 10068 standard [2]. The equations of motion for the model are formulated and solved to compute both the DPMI and absorbed power responses. A constrained minimization function comprising weighted errors of both the DPMI and absorbed power is formulated and solved to identify the parameters. Alternate functions corresponding to different combinations of hand forces are then applied to identify hand-force dependent model parameters.

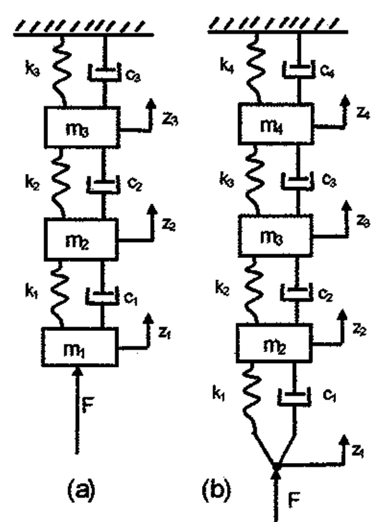


Fig. 1: hand-arm vibration models

Variations in the model parameters are investigated as functions of the grip, push and coupling forces through linear regression analysis. Regression-based models are formulated for deriving the hand-handle forces dependent model parameters. The validity of the model is also examined under selected combinations of hand forces.

Results and Discussions

Comparisons of models results with the measured data suggested that both model structures could predict the DPMI as well as absorbed power reasonably well, when variations in the hand forces are neglected. The model with the visco-elastic interface (b), however, provided relatively poor agreements and large static deflection under a static push force. The model stiffness and damping parameters identified on the basis of measured responses for nine different combinations of hand forces revealed linear variations with the hand forces, particularly the coupling force. The model masses, however, revealed only minimal sensitivity to variations in the hand forces. The resulting relationships between the model parameters and the coupling force (CF) were thus used to formulate a hand force-dependent mechanical-equivalent model of the human hand-arm system using model (a). These relationships suggest linear increase in stiffness and damping coefficients with increasing coupling force, and assume the general form:

$$k_i = a_1 CF + a_0 \text{; and } c_i = b_1 CF + b_0 \quad \text{for } i=1,2,3$$

where a_0, a_1, b_0 and b_1 are constant coefficients. Multiple linear regressions between parameters and the grip and push forces (F_g and F_p) as independent variables, were also performed, which resulted in higher correlation factors (>0.88). These are expressed as:

$$k_i = a_2 F_p + a_1 F_g + a_0 \text{; and } c_i = b_2 F_p + b_1 F_g + b_0 \quad \text{for } i=1,2,3$$

Comparisons of model responses with the measured data revealed reasonably good agreements in both the DPMI and absorbed power magnitudes for the hand forces combinations considered. Consideration of parameters as functions of grip and push forces would also be more desirable than that based upon the coupling force only.

While the DPMI magnitude is known to exhibit negligible sensitivity to variations in excitation magnitude, the absorbed power increases considerably under a higher vibration magnitude. The validity of the resulting model under different magnitudes of excitation was thus explored by comparing the model results with the data acquired under $a_{h,w}$= 2.5 and 5 m/s^2. The model results revealed reasonably good agreements with measured absorbed power and the DPMI under both levels of excitations.

The vibration properties of the proposed models could be considered appropriate in view of the practical issues related to model implementation, namely static deflection, damping ratio and resonant frequencies. The eigen-frequencies of the proposed model also revealed good agreements with the frequencies corresponding to the peaks observed in the DPMI magnitude data, while the static deflections of masses were relatively small.

References

[1] Rakheja, S., Wu, J.Z., Dong, R.G., Schopper, A.W. and Boileau, P.E. 2002: A comparison of biodynamic models of human hand-arm system for applications to hand-held power tools, Journal of Sound and Vibration, 249, pp. 55-82.

[2] ISO 10068, 1998: Mechanical vibration and shock – Free, mechanical impedance of the human hand-arm system at the driving point, International Standard Organization, Geneva, Switzerland.

DYNAMIC RESPONSES OF A FINGERTIP TO VIBRATION - 3D FINITE ELEMENT ANALYSIS

John Z. Wu, Kristine Krajnak, Daniel E. Welcome, Ren G. Dong
National Institute for Occupational Safety and Health, Morgantown, West Virginia, U.S.A.

Introduction

Although the exact mechanisms underlying vibration white finger (VWF) are not clear, it has been speculated that VWF is associated with variations of the blood flow patterns due to the physical damage and/or degeneration in neural and vascular tissue caused by vibration loading [1]. Excessive dynamic deformation of the soft tissues in the fingertip under vibration loading is believed to induce multiple occupation-related hand/finger disorders. However, the in vivo distributions of the dynamic stress/strain of the tissues in the fingertip under vibration conditions have not been studied because they cannot be measured experimentally to date. The goal of this study is to analyze, theoretically, the location and frequency-dependent dynamic deformation of the soft tissue in the fingertip during vibration exposures.

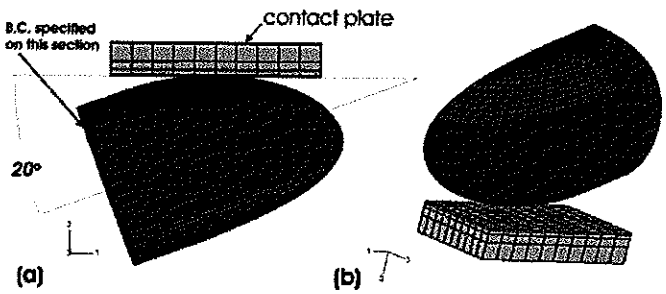


Figure 1: FE model of the fingertip in contact with a flat surface. (a): side view. (b): perspective view. The fingertip is in contact with a flat plate with a contact angle of 20°.

Methods

The fingertip considered in the model is the distal phalanx, the portion from the distal end of the fingertip to the distal interphalangeal (DIP) joint articulation (Fig. 1). The external shape of the fingertip was determined using a smooth mathematical surface fitting to the observed fingertip shapes. The fingertip surface was then scaled to the dimensions of a typical male index finger: length 25 mm, width 20 mm, and height 18 mm. The fingertip was approximated to be symmetric, such that only a half of the fingertip was considered in the FE modeling. The fingertip was assumed to be composed of outer and inner skin layers, subcutaneous tissue, bone, and nail. The soft tissues (inner skin layer and subcutaneous tissues) were assumed to be nonlinearly elastic and viscoelastic, while the bone, nail, and outer skin layer were considered as linearly elastic. The simulations were conducted using a displacement-controlled protocol in two stages. First, the fingertip was statically pre-compressed. The contact plate was first displaced towards the finger to achieve a predetermined value of tissue deformation (i.e., 0.5, 1.0, 1.5, and 2.0 mm). Second, the steady-state dynamics responses of the fingertip were analyzed using a linear perturbation procedure. The fingertip was subjected to a continuous harmonic excitation (magnitude 0.5 mm) from the contact interface. The dynamic analysis was performed in a frequency domain ranging from 16 to 2000 Hz. The frequency-dependent distributions of the vibration magnitude and dynamic strain magnitudes in the soft tissues are investigated.

Results

Typical simulation results for the frequency-dependent distributions of the vibration magnitude in the soft tissues are shown in Fig. 2 (figures show the results with a pre-compression of 2.0 mm). The vibration magnitude at the contact surface is 0.5 mm (specified) for all frequencies, while the vibration magnitudes in the soft tissues are location- and frequency-dependent. It is clear that the fingertip has a major resonance around 125 Hz, at which the vibration magnitudes in the soft tissues are over four times greater than that of the contact plate (0.5 mm). It is interesting to observe that, at this resonant frequency (125 Hz), the soft tissues at the tip has the maximal vibration magnitude while the regions near the contact

NUMERICAL MODELS AND HARDWARE DUMMIES FOR SIMULATING WHOLE-BODY VIBRATION OF HUMAN - AN OVERVIEW

Horst Peter WÖLFEL
Department of Structural Dynamics, Darmstadt University of Technology, Germany

Introduction

The goal of biodynamic models is to simulate the vibration behaviour of the human body. In combination with experimental studies biodynamical models can be a powerful tool for the analysis of the effects of vibration exposure on health [1] and comfort. This paper gives an overview of the state of the art of biodynamic whole-body vibration models of humans, addressing both numerical models and hardware dummies.

Method

Two approaches are distinguished, the phenomenological and the anatomical, as illustrated in Figure 1.

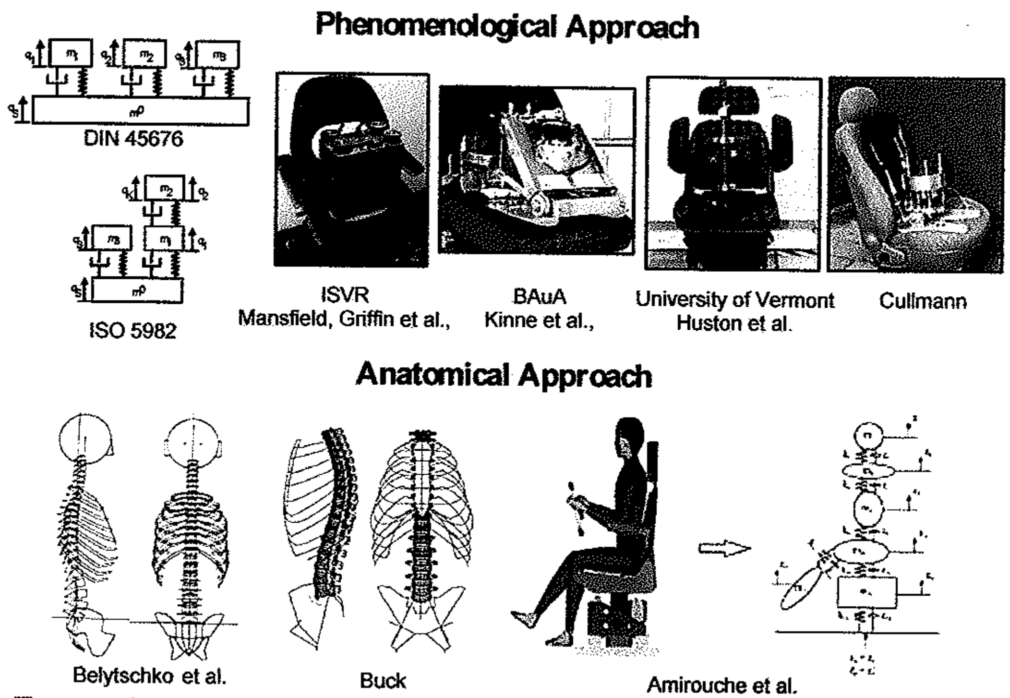


Figure 1: Two modelling approaches.

Phenomenological models aim to reproduce the vibration behaviour of humans with respect to particular physical quantities, chiefly the driving-point impedance at the interface to the seat, and partly with respect to other transfer functions. Discrete systems of masses, springs, and dampers with several degrees of freedom whose topology and parameters are determined by structure- and parameter identification methods are used in the sense that the functions derived from measurements are reproduced as well as possible. This paper provides an evaluation of this methodology and defines its range of application as well as its limits.

The aim of anatomical models, on the other hand, is to simulate numerically all quantities potentially relevant for the evaluation of vibration behaviour, as well as to calculate those unknown quantities not accessible from experimentation, e.g., the loading of the lumbar spine.
The basis for these models is human anthropometry and physiology [2]. Multi-body systems and finite element models are utilised as mathematical models. Because of the complexity of the claim, the validation of anatomical models with the help of experiments on test persons is important. This paper gives an overview of various types of anatomy-based models, their range of application, and the current trends in this field.
Two types of hardware vibration dummies have been developed so far: Passive and active dummies. Both types of dummies aim to reproduce the driving-point impedance at the interface to the seat. Passive dummies consist of a system of masses, springs and dampers. They are based on phenomenological models. Active dummies additionally use an actuator to meet given response functions in a more flexible way.

Results

There is a broad variety of biodynamic models used to simulate human whole-body vibrations [3]. The use of these models requires a critical check of the biodynamic properties employed to describe the models, as well as how they were validated [4].This is most important for numerical models, but also valid for hardware dummies.
In order to accurately simulate motions and loads numerically, including the effects on health and comfort sensations of an individual exposed to vibration, a high level of research is essential. In particular, this necessitates the extension and systematisation of the experimental database needed for the validation of spatial vibration behaviour, and to what extent the dependence of the factors of posture, anthropometric properties, age, gender and potential pre-damage can be systematically calculated.
For anatomy-based models, there is an urgent need for research on the modelling of the lumbar spine, especially with regard to the development of damage models, the modelling of muscles, the influence of muscle activity, and finally the modelling of the inner organs and soft tissue involved in the man-seat interface.

Conclusion

Numerical biodynamic models are needed for any systematic analysis of the relationship between vibration exposure, health and comfort. But the range of their application must be carefully limited to the range in which they are validated. Numerical models and hardware dummies will help to support the development of technical systems for the reduction of vibration impact.

References

[1] ISO 2631-1 (1997) Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General requirements.
[2] BUCK B., WÖLFEL H.P. (1998) Dynamic three-dimensional finite element model of a sitting man with a detailed representation of the lumbar spine and muscles. Computer Methods in Biomechanics & Biomedical Engineering – 2, Gordon and Breach Science Publishers, ISBN 90-5699-206-6, 379-386.
[3] SEIDEL H., GRIFFIN M.J. (2001) Modelling the response of the spinal system to whole-body vibration and repeated shock. Clinical Biomechanics 16 Suppl. No. 1, S3-S7.
[4] GRIFFIN M.J. (2001) The validation of biodynamic models. Clinical Biomechanics 16 Suppl. No. 1, S81-S92.
[5] CULLMANN A., WÖLFEL H.P. (2001) Design of an active vibration dummy of sitting man. Clinical Biomechanics 16 Suppl. No. 1, S64-S72.

SIMULATION OF HUMAN MOTION, MUSCLE FORCES AND LUMBAR SPINE STRESSES DUE TO WHOLE-BODY-VIBRATION: APPLICATION OF THE DYNAMIC HUMAN MODEL CASIMIR FOR THE DEVELOPMENT OF COMMERCIAL VEHICLES AND PASSENGER CARS

Steffen Pankoke and Alexander Siefert
Wölfel Beratende Ingenieure GmbH + Co., Höchberg, Germany

Introduction: Occupant modeling

In the development of commercial vehicles as well as of passenger cars, the effects of vehicle vibrations on operating safety, health and comfort can only be predicted by numerical simulation when appropriate occupant models are available. Such models must be based on human anatomy and have dynamic properties of real humans in order to achieve realistic results. Since human dynamic behavior depend on posture and percentile, the occupant model needs to be adjustable to these parameters with respect to geometry and dynamic properties [1,2].

Dynamic Human Finite-Element-Model CASIMIR

CASIMIR is a non-linear, dynamic finite-element-model of the human body. It consists of a dynamic model of the upper torso with head, neck, shoulders and arms as well as of a dynamic model of the lower extremity with pelvis and legs. The most important part is the lumbar area with dynamic non-linear models of the lumbar spine and of back and abdominal musculature. The frequency-dependent characteristics of the intervertebral discs and the effects of muscle activation and non-linear frequency-dependent muscle properties are included. In the latest stage of development, CASIMIR has been equipped with a compliant model of the body surface in the contact areas to the seat. This results in a very realistic transmission of static and vibrational forces into the human body, see fig. 1. Intense model verification and validation has been performed in all stages of model development, starting with validation of small components like intervertebral disc, ending with validation of whole-body-vibrations using measurements of the dynamic mass / mechanical impedance [4]. For an in-detail examination of stresses in the vertebral bodies and discs, a non-linear submodel of the lumbar spine with an increased number of degrees of freedom can be coupled to the whole-body-model, enabling the researcher to examine local effects of vibrations and single shocks on the lumbar materials.

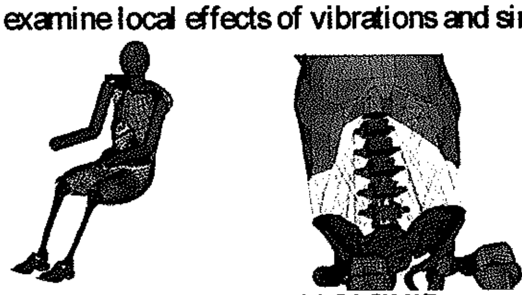


Fig. 1: Dynamic human model CASIMIR

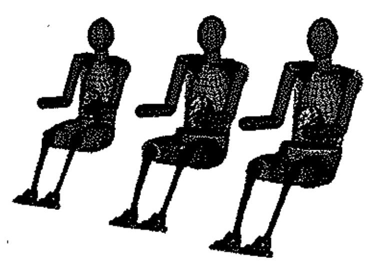


Fig. 2: CASIMIR f05, m50, m95

Since it is well known that human dynamic behavior is significantly affected by anthropometric data and posture, CASIMIR can be individualized to the anthropometric status of single individuals or to the mean values for specific percentile groups. Furthermore, posture can be adjusted to the seating conditions applicable to a specific vehicle. Posture modification capabilities include the variation of the lumbar lordosis [3].

Static Seating: Muscle Activation and Static Forces in the Lumbar Spine

Due to non-linearities of human body and seat a qualified simulation of the static seating procedure is a prerequisite of any simulation of dynamic responses of the human body and seat. During static seating simulation, the human model takes the desired posture on the seat, muscles are activated in order to maintain this posture and thus the non-linear biomaterials of the human body as well as the non-linear foam materials in common seats of commercial vehicles and passenger cars are loaded in an appropriate trim point. This ensures automatic selection of the correct tangent stiffness for the succeeding vibration analysis. A static seating simulation gives a number of valuable results with respect to the human body:

- muscle activation / muscle forces: ergonomic judgment of the body posture
- static forces and static stresses: relevant for damage in the vertebral discs
- pressure distribution (comfort, fig. 3) and H-point-location (package, safety)

Multiaxial Dynamic Excitation: Motions, Forces and Stresses

After static seating simulation, dynamic excitations in multiple axes (x,y,z) can be applied on the human model or the model of the occupied seat (seat + human). Usually, an excitation is selected that is typical for the seat slide (or the seat surface) of the specific vehicle under investigation. For commercial vehicles with higher amplitudes of excitation, a non-linear solution procedure has to be applied while comfort simulations may be covered with linearised procedures. Results to be analysed are motions of the body with respect to operational safety of commercial vehicles, dynamic forces in the musculature with respect to operational performance and dynamic forces / stresses (with submodel) in the lumbar spine with respect to health, fig. 4.

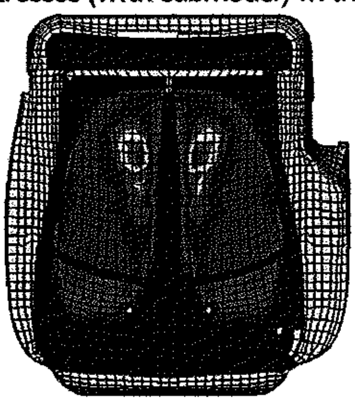


Fig. 3: Static seat pressure

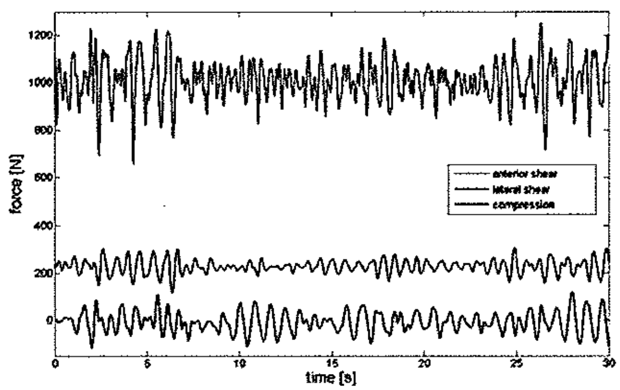


Fig. 4: Dynamic disc forces, spinal level L4L5

References

[1] Pankoke, S.; Hofmann, J.; Wölfel, H. P.: Determination of vibration-related loads by numerical simulation, Clinical Biomechanics 16 Supplement No. 1 (2001)

[2] Seidel, H.; Blüthner, R.; Hinz.B.: Application of Finite-Element-Models to Predict Forces Acting on the Lumbar Spine during Whole Body Vibration, Clinical Biomechanics 16 Supplement No. 1 (2001)

[3] Pankoke, S.; Siefert, A.; Breitfeld, Th.: Numerical Simulation of Seat Vibrations in Luxury-Class Automobiles: Application of the Finite-Element-Man-Model CASIMIR, VDI-Berichte Nr. 1912, VDI Verlag Düsseldorf, 2005

[4] Hofmann, J.; Pankoke, S.; Wölfel, H.P.: Individualisierbares FE-Modell des sitzenden Menschen zur Berechnung der Beanspruchungen bei dynamischer Anregung – Ganzkörpermodell und Submodell LWS, Editor: German Federal Inst. Occupational Safety & Health, Dortmund/Berlin 2003

A CASE STUDY OF WHOLE-BODY VIBRATION EXPOSURES ASSOCIATED WITH ORDINARY PASSENGER AND RECREATIONAL VEHICLES

Robert G. Gibson and Joel D. Gibbons
BBN Technologies, Arlington, Virginia, U.S.A.

Introduction

Measurements and analyses were conducted of whole-body vibration aboard seven commercially available passenger and/or recreational vehicles: sedan; sport-utility vehicle (SUV); pickup truck; moving truck; motorcycle; all-terrain vehicle (ATV); and boat. The purpose of the testing was to measure and assess whole-body vibration exposure in a range of typical vehicle environments in order to gain understanding of typical exposure levels characteristic of activities of daily living.

Vehicle models tested (and model year) were: Ford Taurus (1995); Jeep Cherokee Sport (2000); Toyota Tundra SR5 (2002); Ford F-350 (1997); Harley-Davidson Electra Glide Classic (2004); Yamaha Kodiak 400 4x4; and Steiger Craft Model 21 Montauk. All vehicles were tested with their standard factory-installed seats and were operated under a range of normal operating conditions and speeds typical of intended vehicle use.

Methods

The measurement, processing, analysis, and exposure assessment methods follow the guidance of generally accepted, national and international consensus standards relevant to the evaluation of whole-body vibration, including ISO 2631-1 [1] and ANSI S3.18 [2].

Seats were instrumented with low-mass triaxial accelerometers mounted in seat pads. Accelerometers used in the test are specified to have flat frequency response over the frequency range of 0.5 to 80 Hz, and all accelerometers were recently calibrated traceable to the National Institute of Standards and Technology (NIST). Seat pads were installed following guidance in the relevant standards [1, 2], with sensitive axes of the accelerometers following the standard coordinate system with respect to the seated occupant. (The x-axis represents fore-aft motion; the y-axis represents side-to-side motion; and the z-axis represents vertical motion with respect to the occupant.)

Vibration data processing and analysis, including filtering, sampling, frequency-weighting, averaging, summation, and determination of basic and additional metrics followed procedures in the relevant standards [1, 2]. Digitized time series data were acquired and stored using a PC-based data acquisition system. Whole-body vibration exposure analyses were conducted via post-processing. During data processing, recorded periods of seat acceleration that were identified and verified as resulting from occupant-induced motion rather than vehicle motion were excluded prior to exposure analysis.

The basic evaluation metric for whole-body vibration is the frequency-weighted root-mean-square (r.m.s.) acceleration, a_w. The primary additional evaluation metric is the fourth-power

vibration dose value, VDV. The VDV measured for a period of time can be normalized to a standard eight-hour time period using a standardized calculation process.

Testing of on-road vehicles was conducted on public roads. The routes included a variety of road surfaces and features that are typical of road travel in urban, suburban and/or rural areas. Testing of the ATV was conducted off-road, on rural trails. Testing of the boat was conducted in a bay and estuary in calm conditions with waves of less than one foot. The total duration of vibration measurements during vehicle operations ranged from approximately 1½ hours for the ATV and boat to approximately 4½ hours for the SUV.

Results

Results of basic and additional exposure metrics are summarized in the table below. Basic r.m.s. acceleration is expressed in m/s^2. Measured VDV for the duration of the test and VDV normalized to an 8-hour exposure period (VDV_8) are expressed in $m/s^{1.75}$.

Vfi jdrh	b_{xy}	b_{xz}	$b_{x\{}$	VEWy	VEWz	VEW{	VEW8y	VEW8z	VEW8{
Sedan	0.27	0.21	0.38	4.6	3.8	7.4	6.2	5.2	9.9
SUV	0.14	0.20	0.33	2.9	3.9	6.8	3.4	4.6	7.9
Pickup Truck	0.16	0.19	0.30	3.0	3.8	6.3	3.7	4.7	7.8
Moving Truck	0.22	0.21	0.53	3.8	3.5	11.3	5.2	4.8	15.4
Motorcycle	0.23	0.87	0.61	4.8	14.5	13.9	5.9	17.8	17.1
ATV	0.69	0.67	1.02	9.2	8.9	14.2	14.2	13.7	21.7
Boat	0.66	0.47	1.01	10.0	8.2	22.0	15.0	12.3	33.1

Discussion

Measurements and exposure analyses conducted in accordance with consensus standards may be compared with guidance for the assessment of whole-body vibration and impact with respect to health, as published in Annex B of the standards [1, 2], in order to address questions regarding potential health effects of vehicle operation.

It is also instructive to compare whole-body vibration exposures determined for these typical passenger and recreational vehicles with exposures measured in other vehicle types, including those driven by professional operators, and with other occupational exposures to whole-body vibration and impact. Comparisons may also be made with exposure assessments of vehicles measured by other investigators, in accordance with relevant standards, for example, locomotives and road vehicles, e.g., as reported in [3].

References

1. International Organization for Standardization (1997). Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General Requirements, ISO 2631-1:1997.
2. American National Standards Institute (2002). Nationally Adopted International Standard, Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General Requirements, ANSI S3.18-2002.
3. Fries, R.H., N.K. Cooperrider, and R.E. Larson (1993). Locomotive and Road Vehicle Ride Quality Assessments, ASME Rail Transportation, RTD Vol. 6, pp. 219-227.

PROSPECTIVE STUDIES OF VIBRATION EXPOSED COHORTS: HAND-ARM VIBRATION INTERNATIONAL CONSORTIUM (HAVIC)

M Cherniack[1], AJ Brammer[1,2], R Lundstrom[3], JD Meyer[1], TF Morse[1], G Neely[4], T Nilsson[4,5], D Peterson[1], E Toppila[6], N Warren[1],

[1]Ergonomics Technology Center, University of Connecticut Health Center, U.S.A., [2]Institute for Microstructural Sciences National Research Council Ottawa, Canada, [3]University Hospital Department of Biomedical Engineering and Informatics, Umeä, Sweden, [4] National Institute of Working Life Department of Work and the Physical Environment, Umeä, Sweden, [5]Department of Occupational and Environmental Medicine, Sundsvall, Hospital, Sundsvall, Sweden, [6]Department of Physics Finnish Institute of Occupational Health, Helsinki, Finland

Introduction

HAVIC is a collaboration of investigators from North America, Sweden, and Finland having a scientific mandate from NIOSH, to study the exposure response relationship between vibratory tool exposure and adverse health effects. Five cohorts, the Suomossalmi forest workers cohort, Volvo truck cab workers, Connecticut shipyard workers, and matriculating dental hygiene students and experienced dental hygienists have been under study. In the case of shipyard workers, there was survey and tool exposure data from 1988, although detailed subject testing was only available within the timeframe of the study. The truck cab assembly workforce was an inception cohort that had been followed from 1994 along with age-matched controls. The Finnish forest workers had cumulative health data on a cohort (n=52) that had been studied from 1976. For a subset of these subjects, there was detailed tactometry testing in 1990, 1995, and 2003. Accordingly, there was historical as well as new prospective data for the industrial cohorts. The Suomossalmi cohort was reassembled only for our study, which precluded follow-up evaluation and because of retirement is almost certainly the last time this historic group will be studied. The study features are:

- Characterization of the exposure response relationship for hand-arm vibration through a study design, incorporating multiple cohorts, some having existing historical data,
- Selection of cohorts to include different types of vibration: oscillatory (forest workers) impact (truck cab workers), high frequency (dental hygienists) and mixed (shipyard workers),
- Inclusion of two inception cohorts: dental hygiene students and Swedish truck cab workers,
- Methods for multi-site and historical integration

A description follows.

	Participants	Design	Duration	Populations	Health Assessment	Exposure Assessment
HAVIC	North America, Sweden, Finland	Longitudinal, historical data inclusion, variable re-test intervals	2000-2006	217 shipyard worker; 56 automotive workers/34 controls; 61 forestry workers; 94 dental hygienists/ 56 trainees	Questionnaire, Physical exam, cold challenge test, tactometry, segmental nerve conduction	Diaries, questionnaire, data logging, simulation, biomechanical analysis (PATH)

Methods

Ui f! tuvez! jodmef e! tvswfzt-! qi ztjdbmhf wbmbujpo-! boe! b! tfrfndujpo! pg cbuf sz! pg ïcftu uftutñ!)dpre! di bmfohf! qrhu ztn phsbqi z-! n vnj.gsf r vf odz! ubdupn f uz-! tf hn f oubmtf otpsz! of swf ! dpoevdujpo! wf rpdjuz! \TODW[2,3,4]*! bqqrjf e! bdsptt! hspvqt! up! r vbouigz! sf tqpotf t! up! f yqptvsf/! Fyqptvsf ! n pojupsjoh! jodmef e! f yqptvsf ! di bsbdf sj{bujpo! u spvhi ! ebzmpoh! ebub! mphhjoh! bu! u f ! joejwjevbmtfwf rfl! Workers at each site were instrumented with a microcomputer-based Vibration Exposure Monitoring (VEM) system, developed at the Biodynamics Laboratory of UCHC and about the size of a police walkie-talkie, to record user-specific tool-operating times, vibrations, and grip forces throughout all, or a representative part, of their workday. More specifically, data logging methods involved the direct monitoring of work cycles, involving tool operation time and measures of tool vibration, namely the root-mean-square (RMS), root-mean-quad (RMQ), and root-mean-oct (RMO), and grip forces, each calculated per minute. For this study, the questionnaire was homogenized with other vibration studies[4,5,6]. Cross-translation was directed by the multi-lingual investigators, and then reviewed by the study team. To extend comparability with future international studies, questions! x f sf ! brtp! beef e! gspn ! u f ! Vjcsbujpo! Of uxpsl !)WJOFU*! esbgu! r vf tujpoobjsf -! u f ! qspevdu! pg b! Fvspqf bo!

dpotpsujvn !tqpotpsjoh!vojgpsn !rvftujpoobjsf!efwfmpqnfou!!Evsjoh!uif!jojujbm!tijqzbse!fwbmvbujpo!boe!qjmpujoh-!xf! vofyqfdufemz! gpvoe! b!tfhnfou!tqfdjgjd!ufn qfsbuvsf0wfmpdjuz! sfmbujpotijq[4]/! !Nfn cfst!pg uif!! BWD! dpotpsujvn ! dpodmvefe! uibu dpowfoujpobmhofswf !dpoevdujpo! x bsn joh!ufdi ojrvft!dpvme!op!mpohfs!cf!kvtujgife-!xifsf!uifsf!xbt! tvdi !fydfttjwf!wbsjbcrfi!jotubcjmjuz-!qbsjdvmbsmz!xifsf!wbtdvmbs! eztgvodujpo!xbt!b!qpufoujbmm!qpxfsgvmdpwbsjbuf/!! Uif!qspupdpmx bt!bnfoefe!boe!fyufsobmx bsn joh!x bt!sfqmbdfe!cz!fyfsdjtf.cbtfe!xiprf!cpez!x bsn joh!dpotjtufou xjui !uif!nfui pepmphz!pgX bmjo!)3113*/!!

Results

Uifsf!xbt!ijhi !xpsl gpsdf! wpmbujmjuz/! !Xifo! uif!tijqzbse! xbt!tvejfe! jo! 2: 99-! uifsf!xbt! b! gvmmjn f! hsjoejoh! efqbsunfoutvc.hspvq! pg 571! x psl fst-! pg xipn !82& !i be! wbtdvmbs! tzn qupn t-! boe! 95& !i be! i boe! qbsftuiftjbt/!! Tjhojgjdbou pshboj{bujpobmhdi bohft! uppl ! qmbdf/! ! Cz! 3112-! uifsf! xfsf! pomz! 42! gvmmjn f! hsjoefst<! uif! pwfsbmm qspevdujpo! x psl gpsdf! i be! efdsfbtfe! gspn !8735! up! 2819-! boe! uifsf!xbt! rjm jufe! dpi psu pwfsmbq/!! Uifsf!xbt!brtp! qsphsfttjwf! fyqptvsf! n pejgjdbujpo! ui spvhi ! di bohft! boe! di bohft! jo! x psl ! pshboj{bujpo/! Uif! Tx fejti ! jodfqujpo! dpi psu i be! efdmjofe! gspn !259! up!67! n fn cfst! pwfs! 21! zfbst! x jui pvu b! i jhi ! sbuf! pg uvsopwfs-! bqqbsfoumz! evf! up! uif! ufoefodz! pg zpvohfs! x psl fst! up! tffl ! ejggfsfou! pqqpsuvojujft! fwfo! x jui jo! b! tubcrfi! dpi psu/! Uif! qspcrfn t! pg tzn qupn ! jotubcjmjuz! jo! ti psufs! ufsn ! n fbtvsft! boe! n jojn vn ! pctfswbujpo! qfsjpet!)?6! zfbst! gps! Tvpn pttbm j! boe! Wpmvp*! up! tff! fggfdut! x jui ! pvsl n ptu tfotjujwf! tubcrfi! n fbtvsf!)wjcspubdupn fusz*-! boe! bo! beejujpobrhdpn qmjdbujpo! up! qsptqfdujwf! tuvez! eftjho/!

There are interesting results related to exposure monitoring. In Figure 1, data logged tool operating time is graphed against energy equivalent hand absorption. At the individual level, the association is weak. In Figure 2, there is little correspondence between self report of exposure, data logged exposure, diary based exposure accounting, and observation by a skilled observer.

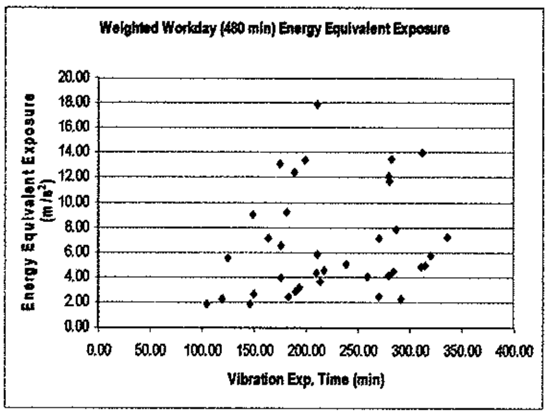


Fig. 1 Exposure magnitude and time

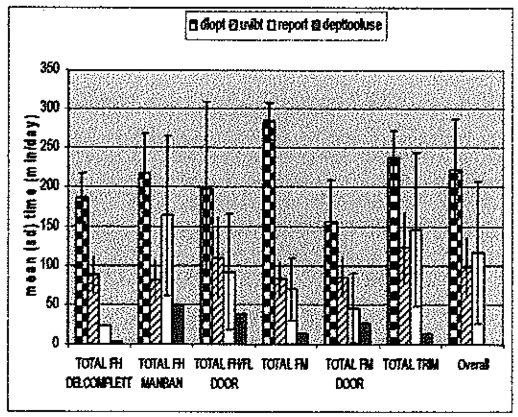


Fig.2 Exposure assessment: different modalities

Discussion

To date, the results demonstrate the importance of exposure monitoring methods. Mixed longitudinal designs or repeated cross-sections have advantages over traditional prospective cohort construction for studies of this type.

References

1. Sakakibara H, et al. Digital nerve conduction velocity as a sensitive indication of peripheral neuropathy in vibration syndrome. Am J Indus Med 1994;26:359-366.
2. Sakakibara H, et al. Affected segments of the median nerve detected by fractionated nerve conduction measurement in vibration-induced neuropathy. Indus Health 1998; 36:155-159.
3. Cherniack M, et al., Segmental Nerve Conduction Velocity in Vibration Exposed Shipyard Workers. Int Arch Occup Environ Health 2004; 77(3): 159-176.
4. Koskimies K, et al. Vibration syndrome among Finnish forest workers between 1972 and 1990. Int Arch Occup Environ Health 1992; 64:251-56.
5. Letz R et al. cross-sectional epidemiologic survey of shipyard workers exposed to hand-arm vibration. Br J Indus Med 1993; 49:53-62.
6. Gemne G., Ed. Stockholm Workshop 86. Symptomatology and Diagnostic Methods in the Hand-Arm Vibration Syndrome. Scand J Work Environ Health 1987; 13S:265-388.
7. Sanden H, et al. Bicycle ergometer test to obtain adequate skin temperature when measuring nerve conduction velocity. Clin Neurophysiol 2005;116:25-27.

CLINICAL ASSESSMENT AND CHARACTERISTICS OF MEN AND WOMEN EXPOSED TO HIGH LEVEL OF HAND-ARM VIBRATION

Thomas Jetzer[1] and Douglas Ketcham[2]
[1]Occupational Medicine Consultants, Minneapolis, Minnesota, U.S.A.
[2]Hospital Radiology Department, St. Paul, Minnesota, U.S.A.

Introduction

While the neurological and vascular aspects of Hand-Arm Vibration Syndrome (HAVS) has been generally accepted as a medical condition, the medical criteria and the clinical findings used to establish the diagnosis has been more difficult to bring to consensus. The criteria was first quantified by the Taylor-Palmear scale.[1] This criteria was subsequently modified in 1986 at the 1st Stockholm Workshop[2,3] to included more acceptance for the neurological effects that characterized the predominate findings in some workers. The relationship between hand-arm vibration and Carpal Tunnel Syndrome was defined in NIOSH 97-141[4].

While the aforementioned documents have defined the clinical entities associated with hand-arm vibration exposure, agreement on the clinical findings and test to confirm the diagnosis has be been more difficult to bring to consensus. Clinicians assessing HAVS has relied on a number of varied neurological and vascular tests. The neurological testing has focused on assessing damage to the sensory capability of the fingers for the neurological component including tests to measuring ability to sense vibration, cold or other end point finger sensor functions. However, the vascular testing has been traditionally focused on the ability to either measure vascular function or to reproduce the vascular blanching that occurs in HAVS with cold water provocation. Recent assessment of this testing in the United Kingdom Coal Miner's study has questioned the value of this testing especially in reviews by McGeoch.[5] In an attempt to provide some type of definitive testing to substantiate vascular damage from hand-arm vibration exposure, angiography is an alternative or adjunct to cold water provocation testing.

The standards that have been established to predict the level, type and incidence of HAVS have been based on clinical studies and reports that have essentially been all male populations. However, the recent entry of women into more vibration intensive jobs has brought about the exposure of some women to high levels of vibration previously only previously experienced by men. However, there have been only few studies that look at HAVS in women[6]. Although exposed the same vibration levels, it has not been clear that the latency and type of pathology of HAVS in women will be the same as for men.

The purpose of this study is to look at recent case studies of men and women exposed to jobs with high levels of hand-arm vibration with extensive clinical testing for both the neurological and vascular components of HAVS as well as other associated upper extremity conditions such as Carpal Tunnel Syndrome.

Methods

Clinical cases referred for evaluation with neurological testing including, vibrometry, Simmes-Weinstein mono filaments, 2 point discrimination, Purdue peg board testing and nerve conduction testing. Vascular testing included Allen's testing, Doppler studies of both upper extremities, cold water provocation testing and angiograph. Additional laboratory blood work and clinical examination was done to rule out alternative disease conditions that could confound results such as diabetes, collagen-vascular disease, etc.[8]

Results

Although the study was too small for statistical significance, review of the cases show that when exposed to the same high levels of hand arm vibration, women develop HAVS symptoms sooner than might be expected and early onset of Carpal Tunnel Syndrome.. In contrast men take longer to develop the same symptoms and are more likely to develop other finding such as tendonitis before they develop the constellation of symptoms and findings found in women.

Comparison of the vascular testing techniques indicates that the angiography can be helpful in confirming the vascular damage from hand-arm vibration exposure in both men and women. Furthermore, angiography may help localize areas of damage from specific exposure. The study proved to be too small to compare the effectiveness the various vascular testing techniques but suggest that further study is warranted.

Discussion

The study shows that there is a suggestion that present standards for the latency of HAVS and other vibration related disorders may be different for women then for men. Also review of clinical cases shows that angiography is useful tool in confirming and defining the level of vascular pathology in case of significant HAVS. Further enlarged studies to confirm both of these findings are recommended.

References

1. Taylor, W and Pelmear, P., eds. Vibration White Finger in Industry. London Academic Press, 1975
2. Gemne, G., Pyykkom, L. Taylor, W. Pelmear P. L., The Stockholm Workshop Scale for the Classification of Cold-InducedRaynaud's Phenomenon in the HAV, Scand. J. Work. Environ. Health, 1987: 13:275-278
3. Bramer, A. J., Taylor, W., Lundborg. G Sensoineuroal Stages of the HAVS, Scand. J. Work. Environ. Health 1987 13: 279-283
4. Musculoskeletal Disorder of the Workplace, US Dept of Health and Human Services, CDC, Natl. Institute for Occupational Health, NIOSH Publ No 97-141 Chapter 5 c, July 1997
5. McGeoch, K.L., et al., A Medical Assessment Process for a Large Number of Miners and Ex-Miners with Compensation Claims for HAVS, 10th HAVS Conference, Las Vegas, June 2004
6. Bylund, S H., Women Injured by Hand-Arm Vibration-Who Cares? 10th HAVS Conference, Las Vegas, June 2004

CHACTERISTICS OF VIBRATION INJURIES IN PERIPHERAL NERVES

Ji-Geng Yan[1], Hani S. Matloub[1], Lin-Ling Zhang[1], James R. Sanger[1], Danny A. Riley[2]
[1]Department of Plastic Surgery, [2]Department of Cell Biology, Neurobiology, and Anatomy, Medical College of Wisconsin, Milwaukee, Wisconsin, U.S.A.

Introduction

This experimental study was done to determine pathological feature of vibration injury to the peripheral nerves in the hind limbs of rats exposed to 7 days of vibration.

Materials and Methods

Animals: Twenty four male Sprague-Dawley rats weighing 350-400 grams were randomly divided into two groups: sham control group and vibrated group. To document vibration-induced changes in the experimental model, the sciatic nerve was used because it contains both motor and sensory fibers and is relatively superficial in the posterior thigh.

Customized Vibrating Platform: The hind limbs of the rats in the vibrated group were exposed to vibration in a custom-built vibrating apparatus consisting of two platforms: a smaller vibrating platform on which the hind limbs of the rat are secured, and a larger platform on which the remainder of the body rests. The vibration parameters (frequency 43.5 Hz, amplitude 1.5mm, acceleration 4.75G, velocity 6cm/sec., and displacement of 3.0mm) of this model were measured.

Methods: Rats were anesthetized with 35mg/kg of intraperitoneal Nembutal (phenobarbital) and their hind limbs fixed to the vibrating platform by Velcro loops. Both hind limbs rest on the vibrating platform while the remainder of the body rests on the larger platform. The rats were vibrated 4 hours a day, for 7 days, with close monitoring of the vibration parameters. The 4-hour duration of hazardous vibration was based on recommendations from the British Standards Institution. The sciatic nerve of rats not exposed to vibration, but similarly anesthetized and secured to the vibrating platform, acted as controls. At the end of seven days of exposure to vibration, nerves from both the vibrated rats and the control rats were harvested after perfusion of the lower half of the body using glutaraldehyde as described below.

Neural Fixation: The aorta was cannulated, and the inferior vena cava was nicked and the animal was initially perfused with 0.9% buffered sodium chloride. This was followed by perfusion of a filtered mixture of 3% glutaraldehyde and 3% paraformaldehyde fixation solution, The tissue was subjected to post fixation by routine. The neural tissue was then submitted for light and electron microscopy.

Results

While light microscopy showed minimal histological differences between vibrated (n=12) and control nerves (n=12), the changes revealed by electron microscopy were dramatic. These included thickening of the epineurium, as well as thickening of the myelin sheath as compared with normal nerve. Also, the axon plasma was detached from the myelin sheaths, and many vacuoles were seen between the myelin laminae(Fig.1); These changes were found in all vibrated animals, and in the whole segment of each vibrated nerve. Myelin balls, consisting of

destroyed myelin rolled into wool-like threads, were located inside the myelin layers (Fig. 2); Axonal damage was seen in both myelinated and nonmyelinated axons (Fig. 3). In addition, nonmyelinated axons were edematous. An interesting finding was the circumferential disruption of several myelin layers, leaving a large circular space around the impacted myelin with central axonal constriction, this characteristic finding, giving the appearance of a finger ring, was found in every vibrated nerve (Fig. 4). Many microtubes and microfilaments were ruptured or had disappeared (Fig. 2-4).

Fig. 1

Fig. 3

Fig. 2

Fig. 4

Fig. 1. Arrow indicates a big vacuole in myelin laminae; **Fig 2.** Arrow indicated a huge myelin ball, wool-like thread consisting of destroyed myelin; **Fig. 3** Axonal plasmadamage was seen in both myelinated (arrow) and nonmyelinated axons (arrow head); **Fig. 4.** Arrows showed a large circular space between the myelin layers.

Discussion

The vibrated nerves show definite pathologic changes in the form of axonal damage and myelin fragmentation[1-4]. We therefore conclude: Myelin disruption, myelin balls, myelin "finger ring" changes, and axonal de-attachment are identifiable characteristics of the neuropathological changes due to vibration injury. Further research to identify the hazardous components of vibration (amplitude, frequency, etc.) is in progress in our laboratory.

Sfgfsfodft!

!

2/! Cpwfo{j! N-! Hjboojoj! G! Spttj! T/! Wjcsbujpo.joevdfe! nvmjgpdbmh ofvspqbuiz! jo! gpsftusz! xpslfst;! frhduspqi ztjprphjdbrtgoejoht!jo!sfrbujpo!up!wjcsbujpo!fyqptvsf!boe!gohfsldjsdvrbujpo/!JouBsdi !Pddvq!Fowjspo! I fbmi /!3111<84)9*;62: .638/!

3/! Utfoh!I N-! Zv!I T-!I p! TU-! Zbp! Ul /! Wjcsbujpo! tzoespn fô qbui pqi ztjprphjdbrhboe! frhduspo! njdsptdpqjd! tvejft/!Lbti tjvoh!KNfe!Tdj/!2: 97<3;843.855/!

4/! Csbn nfs!BK!Qzzl I p!J/!Wjcsbujpo.joevdfe!ofvspqbui z/!Efufdujpo!cz!ofswf!dpoevdujpo!nfbtvsfnfout/!Tdboe!Kl Xpsl !Fowjspo!I fbmi /!2: 98<24)5*;428.433/!

5/! Ebi rjo! MC-! Ofdl joh! MF-! Mvoetupn ! S-! Mvoecpsh! H/! Wjcsbujpo! fyqptvsf ! boe! dpoejujpojoh! rftjpo! fggfdu jo! ofswf t;!bo!fyqfsjn foubm!tuvez!jo!sbu/!Kl boe!Tvsh!)Bn */!2: : 3<28)6*;969.972/!

MEASURING PHYSIOLOGICAL AND BIOCHEMICAL CHANGES IN WORK-RELATED VIBRATION

Ji-Geng Yan[1], Hani S. Matloub[1], Lin-Ling Zhang[1], James R. Sanger[1], Yuhui Yan[1], Danny A. Riley[2], Michael Agresti[1], David Rowe[1], Paula Galaviz[1], Judith Marchant-Hanson[1], Scott Lifchez[1]
[1]Department of Plastic Surgery, [2]Department of Cell Biology, Neurobiology, and Anatomy, Medical College of Wisconsin, , Milwaukee, Wisconsin, U.S.A.

Introduction

Until now there has been controversy about which tests should be performed to diagnose early Hand-Arm Vibration Syndrome (HAVS). Initial screening questions, especially about tingling and numbness, routinely given to patients prior to examinations proved to be a very important tool in the diagnostic process[1, 4]. However, standardized tests that are simple, quick, valid and reliable are needed to support a diagnosis of HAVS. **Purpose:** To find the most valid and reliable tests to diagnose HAVS.

Material and Methods

Five major tests were performed on Group I and Group II. Group I: Control group of 12 volunteers including students, nurses, secretaries and physicians with no history of using vibrating tools (age 20 to 50y, mean age 38.5y; 5male, 5 female.) Group II: 12 workers (age 17 to 65y, mean age 39y; 9 male, 3 female) were sent by a local trade union with a history of using vibrating power tools on their jobs for varying amounts of time (mean 12.2y, from 0.5 to 35y.) Pre-enrollment survey showed that each had more than 4 complaints commonly associated with use of vibrating tools (including numbness, tingling, weakness, pain, finger color or nail changes, temperature change, and difficulty moving.)
1. Sensory nerve conductive tests: Amplitude and nerve conductive velocity (NCV) were evaluated. 2. Cold Stress-Temperature recovery time tests were done on the index finger of the dominant hand following these steps: Confirm water bath is within 4-5° C. Place the finger temperature probe on pad of the index finger of the dominant hand. Record temperature every 15 seconds. Place subject's hand in the cold- water bath for exactly five minutes. Record temperature every 15 seconds for ten minutes. 3. Blood test: Venous blood was taken by a 21-gauge needle with the yellow collection tube adapter. S-ICAM, Sera Thrombomodulin, Norepinephrine levels were evaluated by Henderson Research Centre, Canada. 4. Finger Sensory Evaluation: Semmes-Weinstein monofilament test and 2-point discrimination tests were performed on bilateral fingers. 5. Digital blood pressure test: blood pressure was measured in bilateral index fingers.

Results

1. Median nerve sensory conductive amplitude from palm to wrist :
   GI: mean 96 ± 31μm; GII: mean 43± 30μm; for dominant hands.

   GI vs GII: P<0.001

Motor nerve conductive velocity (NCV) from elbow to wrist:

GI: mean 60.8± 8.5m/s; GII: mean 48.3± 5.9m/s; GI vs GII: P<0.001

2. Cold-Stress Test: Temperature Recovery Rate (TRR) = T before test / T after 10 minutes. GI: mean: 85.36% ± 14.22 GII: More three years of using vibrating tools was a critical point, with vibration for 3 years, the TRR was 70% and as time of use increased, the correlation to TRR also increased. Two subjects' TRR was 52% with 15 and 35 years of using vibrating tools.

3. Sera Chemical Test: A. sICAM: Standard Reference Range is 132.5-344.2ng/mL. GII: The value of 3 workers > 344.2ng/mL (385.2, 346.4 and 381.4), Positive rate was 25.0%; B. Norepinephrine: Standard Reference Range is 0.8-3.4; 4 workers' value was <0.8 nmol/L (0.5, 0.7, 0.3, 0.6). Positive rate was 33.3%.

4. Hand Sensory Evaluation:
   A. Semmes-Weinstein monofilament test: Standard criterion: Normal: 1.65-2.83; Diminished light touch: 3.22-3.61; Diminished protective sensation: 3.84-4.31; Loss of protective sensation: 4.59-6.65.
      Results: 3 workers (3.5years) were normal; 9 workers (>5 years) were diminished. Positive rate was 66.98%.
   B. Two-point discrimination test: Normal is < 6mm. GI: 119/120 tested fingers were less than 6 mm; GII: 20/120 were < 6mm. Positive rate was 16.7 %.

5. Digital blood pressure test: Normal cut-off point: < 70 mmHg was abnormal. Results: GI: none was < 70; GII: 8/23 fingers (n=23, index fingers in both hands, 1 n/a); positive rate was 35%.

Conclusions

1. Semmes-Weinstein monofilament test is a sensitive and simple test to assess HAVS. 2. Cold stress test gave a lower positive rate but did indicate later damage; however, it causes patient discomfort.3. Sensory nerve conductive and NCV were useful but need a control group value.4. The S-ICAM increased in 25%, and NE decreased in 33% of vibrated workers. 5. Digital BP test and 2-point discrimination test both have cut-off point value; they could be used to differentiate HAVS from simple carpal tunnel syndrome.

References

1. Cederlund R, Iwarsson S, Lundborg G. Hand function tests and questions on hand symptoms as related to the Stockholm workshop scales for diagnosis of hand-arm vibration syndrome. J Hand Surg [Br]. 2003 Apr;28(2):165-171.
2. Coughlin PA, Chetter IC, Kent PJ, Kester RC. The analysis of sensitivity, specificity, positive predictive value and negative predictive value of cold provocation thermography in the objective diagnosis of the hand-arm vibration syndrome. Occup Med (Lond). 2001 Mar;51(2):75-80.
3. Coughlin PA, Bonser R, Turton EP, Kent PJ, Kester RCA comparison between two methods of aesthesiometric assessment in patients with hand-arm vibration syndrome. Occup Med (Lond). 2001 Jun;51(4):272-277.
4. Elms J, Poole K, Mason H. A screening questionnaire for HAVS? Occup Med (Lond). 2005 Mar;55(2):139-141.

However, at 2000 Hz (Aβ fibers), restrained animals displayed an increased sensitivity to the stimulus following exposure (i.e., lower CPT value, $F(1, 28) = 23.71$, $p < 0.001$). In contrast, the CPT was significantly higher in vibrated rats immediately following the exposure, indicating that the Aβ fibers were less sensitive to stimulation. However, 24 h later, the CPT at 2000 Hz returned to pre-exposure values (Figure 1A-C). At 5 Hz, there were no group differences in pre to post CPT values. However, about one third of the animals did display a post exposure increase in CPT values. The increased CPT in this subset of animals accounts for the large variability in the post exposure measure at 5 Hz. None of the CPT values were affected by temperature. (Figures 1D-F).

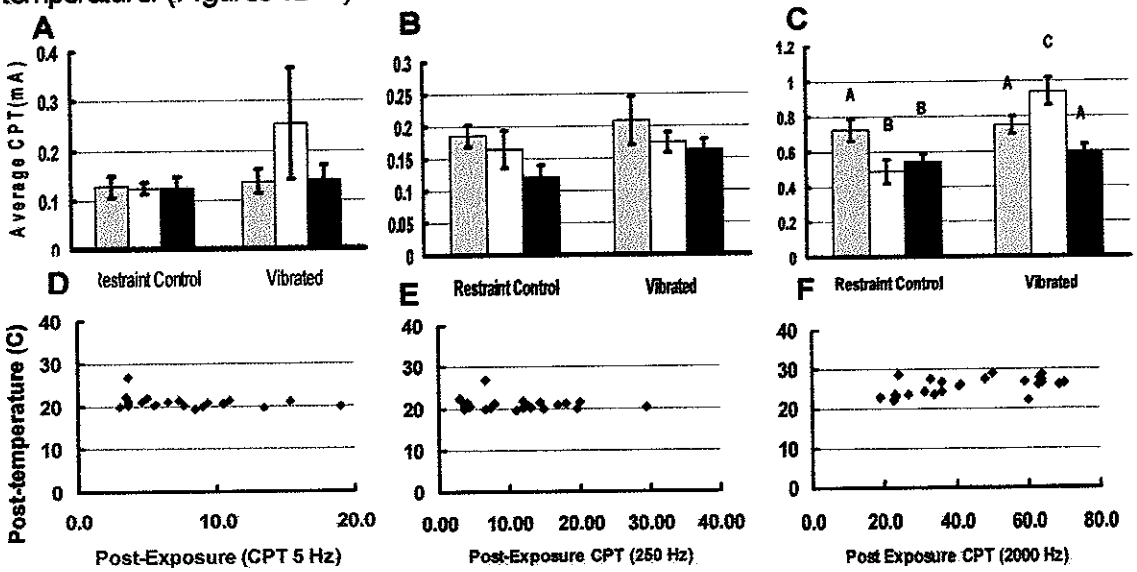


Figure 1. CPT measures (mA) at 5 (A), 250 (B) and 2000 Hz (C), and correlations between temperature and CPT values (D-F). Bars represent the means ± sem. Gray bars are pre-exposure, white immediately after exposure and black 24 h after exposure. In 1-C, different letters are significantly different from each other ($p < 0.05$). R^2 values for the correlation between temperature and CPT are 0.085 for 5 Hz, 0.042 for 250 Hz and 0.009 for 2000 Hz.

Discussion

- Exposure to a single bout of vibration results in a transient reduction in the sensitivity of the Aβ fibers to stimulation. This shift in sensitivity is comparable to the transient shift in vibrotactile thresholds seen in humans after an acute vibration exposure (2,4,5).
- The vibrotactile test is affected by the skin temperature of the subject (1,3). The results of this study demonstrate that the CPT is not affected by skin temperature. In addition, the CPT allows the tester to determine which nerve fiber subtype is affected. Thus, the CPT may serve as reasonable test for diagnosing vibration-induced changes in tactile sensitivity.

References

1. Ide H, et al., Effect of Skin Temperature on Vibrotactile Sensitivity. In: Med Biol Engin Com, 1985, p. 306-310.
2. Kihlberg S, et al., Acute effects of vibration from a chipping hammer and a grinder on the hand-arm system. Occup Environ Med 52: 731-737, 1995.
3. Klinenberg E, et al., Temperature effects on vibrotactile sensitivity threshold measurements: implications for carpal tunnel screening tests. J Hand Surg 21: 132-137, 1996.
4. Lundstrom R, Johansson, R. Acute Impairment Of The Sensitivity Of Skin Mechanoreceptive Units Caused By Vibration Exposure Of The Hand. Ergonomics: 687-698, 1986.
5. Maeda S and Griffin MJ. The growth and recovery of vibrotactile TTs caused by hand-transmitted repetitive shocks of various waveforms. Central European Journal of Public Health 3: 57-61, 1995.

ACUTE EFFECTS OF VIBRATION ON RAT-TAIL NERVES

Sandya Govindaraju, Brian Curry, James Bain, Danny Riley
Department of Cell Biology, Neurobiology & Anatomy
Medical College of Wisconsin, Milwaukee, Wisconsin, U.S.A.

Introduction

Hand arm vibration syndrome (HAVS) affects industrial workers exposed to long term hand-transmitted vibration from powered-tools. Peripheral neuropathy is a major component of the symptom complex of HAVS. Long term exposure to vibration causes myelin damage in peripheral nerves and reduces nerve conduction velocities in rats[1]. This study addresses the effects of acute vibration at constant acceleration of 49 m/s^2 on myelinated fibers in peripheral nerves in Sprague-Dawley male rats using the 'rat-tail vibration model,' which simulates hand-transmitted vibration[2].

Methods

Male Sprague-Dawley rats (~300 g) were assigned to vibration groups: 1 hr continuous vibration at 60 Hz; 4 hr continuous exposure at frequencies of 30, 60, 120 or 800 Hz; immediate and 24 hr following a 4-hr cumulative exposure of continuous and intermittent vibration at 60 Hz. Unanesthetized rats were restrained in cages on a nonvibrating platform with their tails placed on a vibrating stage accelerated by a B&K motor type 4809 and vibrated. Intermittent vibration was delivered in bouts of 10 min vibration alternating with 5 min rest periods repeated over 6 hr. Sham controls were restrained without vibration. After vibration exposure, the rats were anaesthetized, and the ventral nerve trunks from the proximal tail segment 7 were fixed in glutaraldehyde, embedded in epon-araldite and sectioned at 0.5 µm thickness and stained with toludine-blue for morphological quantitative analysis. The total number of myelinated axons in each cross-section of the nerve was counted using the Image J software. Myelin damage was identified by focal increase in area and intensity of toludine-blue staining and unraveling of the myelin sheath. Statistical analysis for comparing sham and the different vibration groups was done using Dunnett's test. Animal treatment and all surgical procedures were approved by the institutional review board and compiled with the Laboratory Animal Welfare Act.

Results

The rats tolerated continuous vibration very well and exhibited no behavioral signs of stress. When exposed to intermittent vibration, there was increased vocalization, a startle reflex at the beginning of each bout of vibration, deposition of porphyrin around the eyes and transient hypersensitivity to touch.

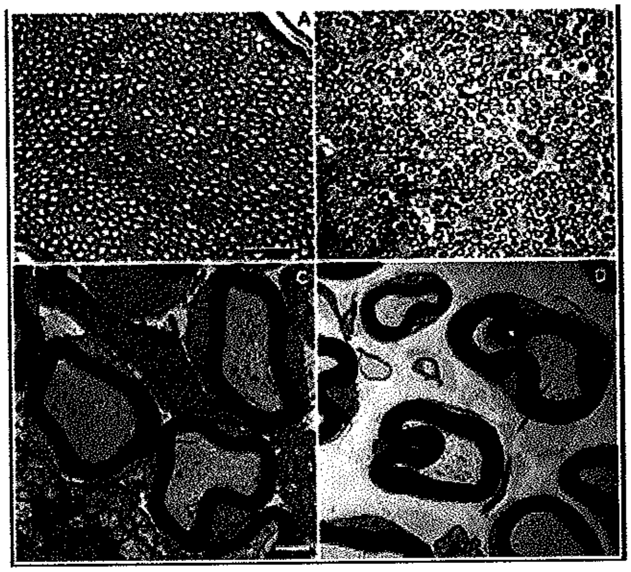


Fig 1: A. The semithin cross section of the tail nerve from a sham control rat demonstrates that the myelin is evenly stained with toludine blue. B. When vibrated, the myelin stains darker and exhibits focal thickening. C. At the electron microscopic level, the myelin membranes are compact, except for tiny foci of separation in the sham-vibrated control nerves. D. Vibrated nerves exhibit larger and more extensive areas of separation of the myelin membranes (arrows), and frequently the myelin sheaths show decompaction (*). Bar in A equals 40 µm for A, B. Bar in C equals 0.5 µm for C, D.

Table 1: There was an average of 1187 ± 50 myelinated axons in the ventral tail nerve at the level of segment 7. The numbers of myelinated fibers showing delamination are expressed as % of total fibers ± SEM. All vibration groups were significantly different from the sham vibrated, *$p<0.05$. CI- Continuous immediate, CS- Continuous 24 hr survival, II- Intermittent immediate, IS- Intermittent 24 hr survival.

Exposure	Myelin disruption %
Sham, 4hrs, CI	5.0 ± 0.6
60Hz, 1hr, CI	15.6 ± 2.2*
30Hz, 4hr, CI	24.5 ± 3.4*
120Hz, 4hr, CI	28.0 ± 1.7*
800Hz, 4hr, CI	16.9 ± 1.6*
60Hz, 4hr, CI	28.6 ± 1.8*
60Hz, 4hr, CS	36.2 ± 1.8*
60Hz, 4hr, II	47.7 ± 1.9*
60Hz, 4hr, IS	45.3 ± 5.7*

Discussion

1. Vibration exposure duration as short as 1 hr at 60 Hz can cause myelin disruption.
2. Damage is not limited to a single frequency.
3. Frequent rest periods do not reduce, but exacerbate, damage as evidenced by increased myelin disruption and transient hypersensitivity.

References

1. Chang KY, Ho ST, Yu HS. Vibration induced neurophysiological and electron microscopical changes in rat peripheral nerves. Occup Environ Med 1994; 51:130-135.

2. Curry BD, Bain JL, Yan JG, Zhang LL, Yamaguchi M, Matloub HS, et al. Vibration injury damages arterial endothelial cells. Muscle Nerve 2002; 25:527-534.

Supported by the Medical College of Wisconsin and in part by NIOSH grant R01 OH003493

Podium Presentations

Session V: Health Effects III

Chairs: Thomas Jetzer and Danny Riley

SEATED HUMAN RESPONSE TO SIMPLE AND COMPLEX IMPACTS

D Wilder, T Xia[1], J Ankrum, K Spratt[2]
Iowa Spine Research Center, Biomedical Engineering Department,
[1]University of Iowa, Iowa City, Iowa, U.S.A.
[2]Orthopaedics, Dartmouth College, Hanover, New Hampshire, U.S.A.

Introduction

The human lumbar spine is inherently an unstable structure and requires sophisticated neuromuscular control to maintain its stability and for performing physical tasks. As a consequence, it is important to understand the potential health effects on human operators of mechanical stimuli such as shock and vibration.[1] Impact applied to a vehicle operator combines the risk of sudden, unexpected load with the mechanical stress of the seated posture.[2] Because many work environments contain the potential for multiple, unexpected impacts, it is important to understand how the trunk muscles respond to complex conditions. We believe the results have implications for isolation design and standards development.

Methods

Muscle activity was recorded during simple and complex impacts, applied randomly and without warning, while subjects sat on an air-suspension truck seat located on a man-rated 6-DOF motion platform (Rexroth-Hydraudyne). Simple (single) impacts consisted of 100 ms quarter-sine jolts in the side-to-side (L and R) and vertical upward (V) directions with peak amplitude at 0.4 g. Complex impacts consisted of combinations of two simple (single) impacts in sequence (LV, RV, VL, VR), separated by 100 ms. Twelve right-handed males (23.7 ± 7.8 years old) were tested without a blindfold under 2 posture conditions (supported while leaning back and unsupported, sitting upright) and 2 seat suspension conditions (present or absent). Each type of impact was repeated three times under each posture and suspension condition, resulting in 84 impacts in total. Surface EMG signals from the left and right erector spinae (ES), rectus abdominis (AR), external obliques (EO) and internal obliques (IO) were recorded and transformed to 25ms RMS values. The response time, defined as the time the muscle activity exceeded the mean + 2 STD of the pre-impact resting period, peak response amplitude, and time were then derived. A mixed-model repeated measures analysis of variance was used to evaluate statistical significance, where type I error rate was set at .05.

Results

One question we asked of these data was whether there were differences in responses related to simple single strike impacts (L, R, or V) and complex, double-strike impacts (LV, RV, VL, VR). There are 21 possible combinations of comparisons of simple and complex impacts to each other. The differences found are listed in Table 1.

Table 1. Number of significant contrasts in muscle response to different impact types (the format below is: Peak response amplitude (response start time, time at peak response)

	Muscle Groups				
Comparison	ES	AR	EO	IO	Total
Simple vs. Simple	1 (0, 0)	0 (0, 0)	1 (0, 1)	3 (2, 2)	5 (2, 3)
Simple vs. Complex	3 (3, 4)	2 (0, 0)	1 (3, 1)	5 (5, 6)	11 (11, 11)
Complex vs. Complex	0 (3, 2)	0 (0, 0)	0 (2, 0)	2 (4, 5)	2 (9, 7)
Total	4 (6, 6)	2 (0, 0)	2 (5, 2)	10 (11, 13)	18 (22, 21)

The contrast between impact types shows differences in the muscles. Overall differences occurred more often in the Simple vs. Complex comparisons. The analysis also showed that posture had a significant effect but the suspension had little effect.

Discussion

These results corroborated prior work showing that the back muscles play an important role in balancing the trunk in seated impact environments and confirmed that abdominals and external obliques are less able to discriminate between impact types and are likely unable to respond effectively. This study shows, for the first time, that the behavior of the internal obliques is more sensitive than that of the erectors to impact types. Just as a bent beam has one side under tension and the other side under compression, the act of sitting for a human lengthens the posterior aspect of the body and shortens the anterior aspect. During sitting, the lengthened (posterior) muscles are more sensitive and the passively shortened and hence, loose anterior muscles are less sensitive. In the standing posture, all trunk muscles play a role in postural control, however in the sitting posture, a demand on the internal obliques was observed. Long-term exposure to this unbalanced condition may retrain the muscles and control system in an undesirable fashion. Concern about responses to a complex strike is because the first impact may displace the body and the second may further destabilize it, especially with the first strike being an asymmetric impact. These results suggest that a single strike from the side may not be a simple mechanical stimulus, as has traditionally been hypothesized, because it is asymmetric and fundamentally different from a vertical strike. There was one limitation of the study. The low level of the impacts might have contributed to a lack of suspension effect.

Acknowledgements This project entitled "Reducing Injury Risk from Jolting/Jarring on Mobile Equipment" was partially supported by CDC order # S0265112 from the NIOSH-Spokane Research Lab, Centers for Disease Control and Prevention. This investigation was conducted in a facility constructed with support from The University of Iowa vice president for Research and the University of Iowa, College of Engineering. Assistance was provided by Logan Mullinix (CVGrp, Columbus, OH) in determining subject impact exposure and in supplying a KAB seat.

References

1. Wilder DG, Pope MH (1996) Epidemiological and aetiological aspects of low back pain in vibration environments - an update. Clinical Biomechanics, 11(2):61-73
2. Wilder DG, Aleksiev AR, Magnusson ML, Pope MH, Spratt KF, Goel VK (1996) Muscular response to sudden load: A Tool to Evaluate Fatigue and Rehabilitation. Spine 21:2628-2639

RESPONSE TO SUDDEN LOAD BY PATIENTS WITH BACK PAIN

D Wilder[1], T Xia, R Gudavalli[2], E Owens[2],
[1]The University of Iowa, Iowa City, Iowa
[2]Palmer Center for Chiropractic Research, Davenport, Iowa

Introduction

As mechanical shock and vibration environments evolve, it is important to understand their potential effect on human operators. Human beings are sophisticated mechanisms comprised not only of passive components with mass, damping, and stiffness characteristics, but also of components that can actively affect apparent mass, stiffness, and damping. Because the lumbar spine can exhibit local, short-column buckling, stability of the human trunk depends on the responsiveness of the neuromuscular control system.[1-2] We have been evaluating the ability of patients with back pain to respond to a series of sudden loads. We believe the results have implications for isolation design and standards development.

Methods

153 patients, aged 21 to 55, presenting with back pain agreed to enroll in a research study that randomly assigned them to one of three treatment arms: high velocity low amplitude spinal manipulation, low velocity variable amplitude spinal manipulation, or wait for 2 weeks and then be randomized to one of the above groups. Response to sudden load testing was one of a battery of baseline evaluations performed upon entry into the study and prior to treatment. EMG electrodes were attached to the skin over the paraspinal muscles of the standing participant bilaterally 3 cm from midline at the L3 level. While standing upright on a force plate (Bertec), participants were fitted with a strap around their back and hooked to a load cell in front of their chest. An accelerometer was rigidly attached to the load cell. Impact was applied to the chest using a cord attached to a falling weight. The weight's fall distance was varied between 9 and 13 inches to account for the size of the subject. The subject was blindfolded and wore headphones playing white noise to prevent cueing of when the weight was dropped to apply the load. Hence, although the participant knew a load was about to be applied, he or she did not know the instant it would occur. Just before the weight was dropped, a 4 second data collection process was started for the two EMG electrodes, load cell, accelerometer, and force plate. The load drop was repeated 6 times, at irregular intervals, over a period of 2 minutes. The raw data thus collected was reduced to obtain several values: 1) length of time from the pull on the harness to the beginning of the response of the left and right paraspinal muscles (LES, RES), 2) time and magnitude of the maximum response, 3) force and acceleration experienced at the chest, and 4) the time and magnitude of the center of pressure location (COP). A general linear model was used to evaluate the results.

Results

For the EMG data, of the 1,824 observations made, 90% of them indicated a response. Prior to the sudden load, resting muscle activity was different between left and right sides (p=0.0001) and between males and females (p=0.0001). Female subjects began to respond to the sudden load within 92 to 110 ms and males from 101 to 109 ms. Females exhibited more variation in starting

their responses than did males. Females began to respond to the second sudden load significantly sooner (92 ms) than the males (109 ms) with p=0.0027, otherwise they were similar to the males. There was no significant effect of sudden load trial (1st, 2nd, 3rd, etc) on the amount of time taken to create the peak EMG response to the sudden load (179-193 ms LES, 186-198 ms RES), but the muscle side responding more quickly had a trend of an effect (p=0.0568). Peak muscle response was not affected by gender, but was affected by trial. The first peak response differed significantly from the rest (2nd p=0.0108, 3rd-6th p<0.0001). Thereafter, only the peak response at trial 2 was different from that at trial 6 (p=0.0498). Females exhibited greater variation in their peak responses than did males. The females experienced significantly lower forces at the chest during the sudden pull than did the males (121.1 v 131.4 N, p<0.0001). The females experienced significantly larger accelerations at the chest during the sudden pull than did the males (1.76 v 1.39 ms^{-2}, p<0.0001). In response to the sudden load, subjects counteracted the overturning moment by shifting forward the center of pressure (COP) under their feet. The shift was larger in the first trial (84mm) and decreased over the trials (79, 77.2, 75.4, 74.7, and 73.7 mm). The time to shift the COP forward was smallest in the first trial (388.0 ms), increased up to the 5th trial (433.4, 444.1, 480.6, and 488.4 ms), and then decreased slightly by the 6th trial (486.5 ms).

Discussion

In a study trying to predict who would respond well to different chiropractic treatment methods, baseline data were obtained on patients that provide insight into the response of people with back pain to sudden loads applied at the chest. The primary observation is that people take finite amounts of time to respond to a sudden load. People are able to adapt to some aspects of exposure to a train of sudden loads: adjusting back muscle activity magnitude, and the speed and magnitude of changing the center of pressure in order to stabilize their stance. There is however, no significant adaptation of the time the back muscles take to respond to the load. Although efforts were made to adjust the suddenly applied load according to subject size, the females presented a more compliant and faster moving trunk to the loading device. In summary, although people with back pain can make some adaptations to a train of similar impacts, their first response is always unique. It always takes a certain amount of time to respond to various aspects of sudden load. The reciprocals of the above response times provide insight into some of the observed psychophysical and mechanical sensitivities to vibration and repetitive mechanical shock.

Acknowledgements Under the leadership of Dr. William Meeker, this project entitled: Predicting Patients' Response to Spinal Manipulation, was supported by Grant Number U19 AT002006 from the National Center for Complementary and Alternative Medicine (NCCAM). This investigation was conducted in a facility constructed with support from Research Facilities Improvement Program Grant Number C06 RR15433-01 from the National Center for Research Resources, National Institute of Health. Several others were also vital to this project: Mr. Lance Corber of the Office of Data Management for organizing the biomechanical data, Dr. Maria Hondras, Project Manager, Caelyn Nagle, Josh Myers, several other assistants in data collection and management, recruitment assistants, and clinicians.

References

1. Wilder DG, Pope MH, Frymoyer JW (1988) The biomechanics of lumbar disc herniation and the effect of overload and instability. American Back Society Research Award. J Spinal Disorders 1(1):16-32
2. Wilder DG, Aleksiev AR, Magnusson M, Pope MH, Spratt K, Goel V (1996) Muscular response to sudden load: A tool to evaluate fatigue and rehabilitation. Spine 21(22):2628-2639

UPPER BODY JOINT COORDINATION UNDER VIBRATION

Jueun Lee, Jong-Hwa Yoon, K. Rider, Bernard J. Martin

Introduction

Whole body vibration is known to affect movement accuracy [1], however little is known about changes in the organization of movement and movement strategies used to limit the influences of perturbations. The specific aim of this work is to analyze the motion and coordination of upper body segments of seated operators performing reaching tasks under whole-body sinusoidal vibration exposure and simulated vehicle ride motion. The long-term objective is to model reach coordination and predict the dynamic behavior of the upper body motion under vehicle vibration exposure.

Method

The reach task consisted of pointing with the right hand index finger to targets located on touch screens placed in front of the subject, 45° overhead and 90° to the right in the mockup cabin of an HMMWV placed on a 6 DOF ride motion simulator. The task was performed under stable (no vibration) and vibration (sinusoidal vibration or simulated ride motion) conditions. A motion capture system was used to record kinematic data of reflective markers to recreate body link trajectories. Joint angles (torso, shoulder and elbow; Figure 1) were then computed using quaternions. Coordination between body links was defined as a) the joints angle-versus-angle relationships between the upper arm and lower arm, and b) the joint motion onset relationships between torso, upper arm and lower arm in the time domain.

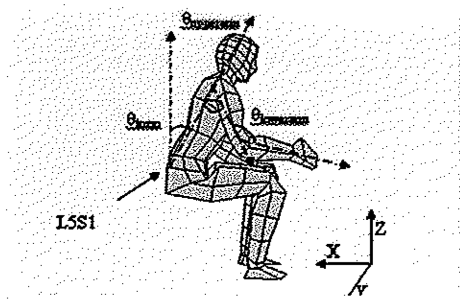


Figure 1. Angle definitions

Results

Angle–versus-angle relationships. The relationship between upper arm vs. lower arm angle and torso vs. upper arm angle for a far forward reaching movement in the stable (solid lines) and vibration conditions (dotted lines) are illustrated in Figure 2. Fig 2A compares the control condition with a 4 Hz lateral vibration while Fig 2B compares the control condition with a 6 Hz vertical vibration. It appears that under vibration exposure the reduced upper arm extension is compensated by an increase in torso flexion. This effect is seen in the last phase of the movements (encircled areas). In addition, the lower arm extension is delayed under 6 Hz vertical vibration (Fig 2B left panel).

Time of joint motion onset. The timing relationship between torso, upper arm and lower arm is largely a function of the target to be reached. Examples of delays between body links are illustrated in Figure 3. The control condition is compared to a 6 Hz vertical vibration for three

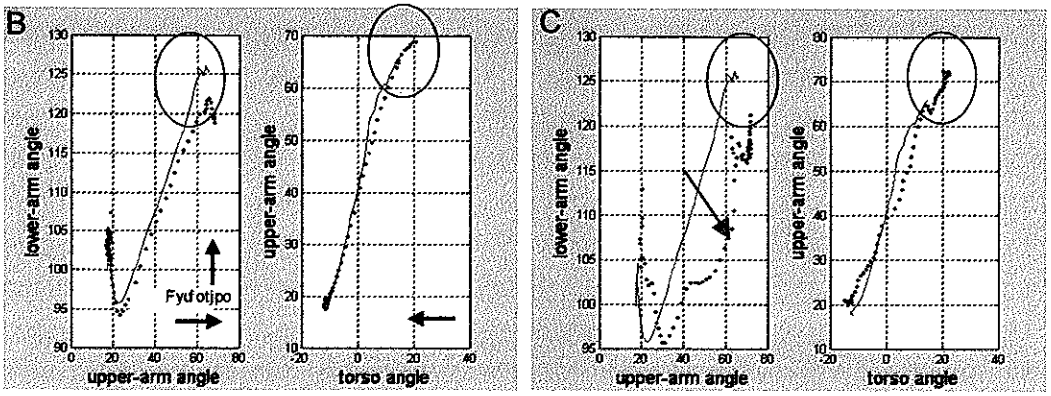
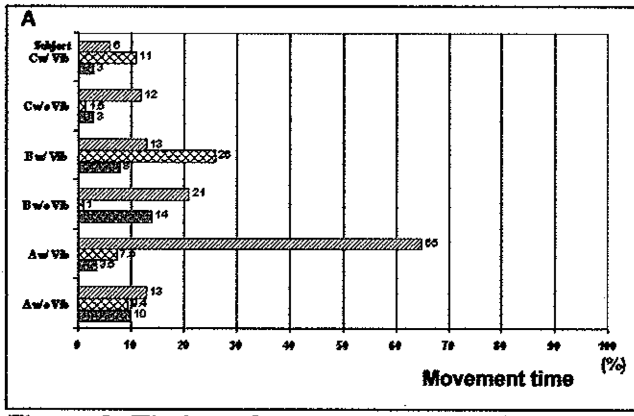


Figure 2. Angle-versus-angle relationships for a far forward reach in two vibration conditions. A: lateral direction, 4 Hz, 0.2g vibration. B: vertical direction, 6 Hz, 0.2g. [control: solid line; vibration: dotted line]

subjects reaching to a lateral target. For this target, the upper arm moves first in the control condition while the torso moves first under vibration exposure.



B

Without Vibration	With Vibration
Torso 1 (0) 2 (3) 3 (0)	Torso 1 (3) 2 (0) 3 (0)
Upper Arm 1 (3) 2 (0) 3 (0)	Upper Arm 1 (0) 2 (1) 3 (2)
Lower Arm 1 (0) 2 (0) 3 (3)	Lower Arm 1 (0) 2 (2) 3 (1)

Figure 3. Timing of movement onsets for a lateral near reach. A) movement onset times (torso: dotted bar; upper arm: bar with the x; lower arm: diagonal bar); B) order of movement onset.

Discussion

Overall the results indicate that the movement strategies (magnitude and timing of joint movements) change under vibration exposure; however, these strategies are dependent on movement direction. It is assumed that the forward flexion of the torso may be used to reduce the influence of vibration on the perturbation of the arm movement.

Reference

Gauthier, G.M., Roll, J.P., Martin, B., Harlay, F. (1981) Effects of whole-body vibration on sensory motor system performance in man. Aviat Space Environ Med 52(8): 473-479.

FGGFDUT!PG!TI PSU.UFSN!FYQPTVSF!UP!X I PMF.CPEZ!WJCSBUJPO!PO!
X BLFGVMOFTT!

!

Zvl b!Tbupv-!I jefp!Boep-!Ubutvzb!Jt i jubl f!
Efqbsun foupg!Fowjspon foubrtN fejdjof-!L vsvn f!Vojwf stjuz!Tdi pprupgN fejdjof-!!
L vsvn f-!Kbqbo!

!

Jouspevdujpo!

!

X i prf.cpez!wjcsbujpo!pddvst!x i f o!ui f!cpez!jt!tvqqpsuf e!po!b!tvsgbdf!x i jdi !jt!wjcsbujoh/! Pddvqbujpobrt!fyqptvsf!up!x i prf.cpez!wjcsbujpo!n bjorz!pddvst!jo!ui f!usbotqpsubujpo!joevtusz-!cvu brtp!jo!bttpdjbujpo!x jui !pui fs!joevtusjbrt!qspdfttt/! Fqjefn jprphjdbrt!tuvejft!i bwf!gsfrvfoumz! joejdbuf e!bo!f rfwbuf e!i fbri !sjtl !gps!ui f!tqjof!jo!x psl fst!fyqptf e!up!x i prf.cpez!wjcsbujpo/!X jui ! sfhbsejoh!up!usbjo!ps!cvt!pqf sbupst-!b!gbnjrpg!esjwf st!x bl fgvrof tt!rfwfrt!cf dbvtf!pg!gbujhvf!jt!pgf o! qpjouf e!pvu/!Ui jt!efdsfbtf!jo!x bl fgvrof tt!sftvmt!jo!bo!jodsfbtf!pg!ui f!pddvssfodf!pg!bddjef out/! I px fwfs-!b!tuvez!pg!i px !x i prf.cpez!wjcsbujpo!bggf dut!qf pqrf(t!rfwf rt!pg!x bl fgvrof tt!i bt!opu cf f o!epof/!Up!uf tu!ui f!i zqpui ftjt!ui bu!fyqptvsf!up!x i prf.cpez!wjcsbujpo!i bt!b!dfsubjo!fggf du!po! rfwf rt!pg! x bl fgvrof tt-! ui f! di bohf! pg! b! tvclf dujwf! x bl fgvrof tt! rfwf rt! boe! di bohf t! pg! f rfduspf odf qi brphsbn !)FFH*!x fsf!pctf swfe!voefs!fyqfsjn foubrt!fyqptvsf!up!ti psu!ufsn !x i prf. cpez!wjcsbujpo/!!

!

N fui pet!

!

Tvclf dut!bsf!uf o!i fbrui z!n brf!vojwf stjuz!tuvef out-!x jui !bo!bwf sbhf!bhf!pg!31/8!≥!2/9!zf bst! pme-!boe!ui f z!bsf!brr!opotn pl f st/!Vtjoh!ui f!frvjqn fou!)DW411-!BLBTI J*!pg!x i prf.cpez! wjcsbujpo!hf of sbups-!x f!dpotjefs!bo!fyqptvsf!fowjspon foupg!bduvbrt!esjwf s!x psl -!tp!ui bu!tf ui f! gsfrvf odz!boe!ui f!bddf rfsbujpo!rfwf rt!bt!21!I {!boe!1/7n t^{-3}!s/n /t//!Ui f!tvclf dut!x f sf!fyqptf e!up! x i prf.cpez!wjcsbujpo!jo!ui f!tf buf e!qptjujpo!boe!fyqptvsf!ujn f!x bt!gjyf e!gps!23!n jovuf t/! Tvclf dujwf!x bl fgvrof tt!rfwf rt!x bt!f wbmvbuf e!vtjoh!ui f!r vf tujpoobjsf!pg!WBTT!)Wjtvbrt!Bobmph! Trff qjof tt! Tdbrf*! boe! LTT!)Ui f! L x botfj! Hbl vjo! Trff qjof tt! Tdbrf*/! Gps! ui f! f rfduspf odf qi brphsbn !)FFH*!n fbtvsf n fou!ju!x bt!frvjqqf e!x jui !ui f!f rfduspef t!cbtf e!po!ui f! Jouf sobujpobrt!uf o.ux fouz!f rfduspef!tztuf n !)D4.B3-!P2.B3-!P3.B2*/!FFH!bdujwjuz!jo!ui f!brqi b! gsfrvf odz!cboe!)9!ò!23!I {*!jt!pof!pg!ui f!n ptu!uzqjdbrt!qi ztjprphjdbrt!joejdbupst!x i jdi !sfqsftf ou!ui f! usbotjujpo!gspn !x bl fgvrof tt!up!trff qjof tt/!BBU!)Brqi b!Buf ovbujpo!Uf tu*!x i jdi !sfqf bu!ui sff! ujn f t!f bdi !pqf of e!boe!drptf e!f zf !gps!2!n jovuf!x bt!qf sgpsn f e!jo!b!tf bujoh!qptjujpo!x jui ! ejsf dujpot!pg!ui f!sftf bsdi f s!jo!ui f!cf hjoojoh-!jo!ui f!n jeerf!boe!jo!ui f!foe!pg!fyqptvsf!up!x i prf. cpez!wjcsbujpo/!Gps!bobrztjt-!qpx f s!tqf dusbrt!bobrztjt!x bt!dpoevdufe!pwfs!ui f!rbtu!7!n jo!pg!FFH-! boe!x bl fgvrof tt!rfwf rt!x f sf!efgjof e!bt!ui f!sbujp!pg!n fbo!brqi b!qpx f s!evsjoh!f zf t!drptf e!wfstvt! f zf t!pqf of e/!Ui f!rbcpsbupsz!x bt!l f qu!bu!sppn !uf n qf sbuvsf!)32!≥!2/1!ef hsf f t!D*-!i vn jejuz!x bt! 61!≥!6&-!opjtf!rfwf rt!x bt!74/7!eC!)B*!f r-!boe!jmmn jobujpo!621!my/!Fbdi !fyqfsjn fou!x bt!tubsuf e! bspvoe!21;11!bn !up!n jojn j{f!ui f!f ggf dupg!cjpsi zui n /!

!

Sftvmut!

!

WBTT!boe!LTT!jodsfbtfe!boe!tvckfdujwf!rvfwfmpg!xbl!fgvmoftt!efdsfbtfe!gspn!qsf.!up!qptufyqptvsf!jo!bmm!tvckfdut-!sfhbsemftt!pg!fyqptvsf/!Vtjoh!uif!BBU!bt!bo!pckfdujwf!xbmlfgvmoftt!nfbtvsf!bmtp!tipxfe!uibu!xbmlfgvmoftt!rvfwfmt!xfsf!sfevdfe!bu!uif!qptufyqptvsf!uftu!jo!bmm!tvckfdut/!!Ipxfwfs-!xbmlfgvmoftt!rvfwfmt!xbt!bmmptu!dpotubou!jo!uif!dbtf!xjui!pvu!fyqptvsf!up!xiprn.cpez!wjcsbujpo!boe!jo!uif!dbtf!xjui!fyqptvsf!up!xiprn.cpez!wjcsbujpo!gpmmpxjoh!sftu-!boe!ju!xbt!sjtjoh!bgufs!uibu/!Npsfpwfs-!uif!dbtf!xjui!fyqptvsf!up!xiprn.cpez!wjcsbujpo!xbt!b!tjhojgjdboumz!ejggfsfodf!gspn!uif!dbtf!xjui!pvu!fyqptvsf!up!xiprn.cpez!wjcsbujpo/!!

!

Ejtdvttjpo!

!

Ju!jt!ejggjdvmu!up!tjnvmbuf!uif!fybdu!fowjspονfou!uibu!esjwfst!bsf!fyqptfe!up!jo!usbotqpsubujpo!wfijdmft!jo!uif!mbcpsbupsz/!!Ipxfwfs-!jo!uijt!tuvez-!fyqptvsf!up!xiprn.cpez!wjcsbujpo!xbt!tjnvmbufe!tp!uibu!uif!fggfdut!po!xbmlfgvmoftt!dpvme!cf!nfbtvsfe/!Xf!efnpotusbuf!uibu!xbmlfgvmoftt!rvfwfmt!dibohft!xjui!fyqptvsf!up!xiprn.cpez!wjcsbujpo/!Cbtfe!po!uiftf!sftvmut!xf!tvhhftu!uibu!bufoujpo!tipvme!cf!gpdvtfe!po!sfevdjoh!xiprn.cpez!wjcsbujpo!fyqptvsf/!Uijt!nbz!efdsfbtf!uif!sjtl!pg!bddjefout!dbvtfe!cz!b!esjwfs(t!wjcsbujpo.joevdfe!sfevdujpo!jo!xbmlfgvmoftt!rvfwfmt/!

!!

Sfgfsfodft!

!

Ojtijzbnb!L!)3116*!Sfwjfx!pg!Tuvejft!po!uif!Fggfdut!pg!Ivnbo!Fyqptvsf!up!Xiprn.Cpez!Wjcsbujpo!boe!uif!Qspcmfn!pg!Vqebujoh!uif!Sfmfwbou!Fyqptvsf!Mjnjut/!KTqj!Mbcpvs!92-!83.95!)jo!KbqbofTf*/!

Cbmmfs!L-!Hsjggjo!N-!Cboofuu!C/!)3111*!Qsfwbmfodf!boe!Cbufsojo!pg!pddvqbujpobm!fyqptvsf!up!xiprn!cpez!wjcsbujpo!jo!Hsfbu!Csjubjo.!gjoejoht!gspn!b!obujpobm!tvswfz/!Pddvq!Fowjspo!Nfe!68-!33:.!347/!

Cbmmfs!L-!Hsjggjo!N-!Tzeeboll!/!)3114*!Uif!sfmbujwf!jnqpsubodf!pg!xiprn!cpez!wjcsbujpo!boe!pddvqbujpobm!mjgujoh!bt!sjtl!gbdupst!gps!mpx.cbdl!qbjo/!Pddvq!Fowjspo!Nfe!71-!826.832/!

Kpi boojoh!F/!)2::2*!Cbdl!ejtpsefst!boe!ifbmui!qspcmfnt!bn!poh!tvcx bz!usbjo!pqfsbupst!fyqptfe!up!xiprn.cpez!wjcsbujpo/!Tdboe!Kpg!Xpsl!Fowjspo!boe!Ifbmui!28-!525.52:/!

Nj{vlbnj!O-!Tbupv!L-!Lvsbnbub!U-!Tbxb!N!)3114*!Fyqfsjnfoubm!Tuvez!po!uif!Sfmbujpotijq!Cfuxffo!Dbsejpwbtdvmbs!Gvodujpot!boe!Bvupopnjd!Ofswpvt!Tztufn!Voefs!Qspmpohfe!Sftusbjofe!Dpoejujpo/!Kqo!Usbotqpsubujpo!Nfe!68.2.8!)jo!KbqbofTf*/!

Jtiji bsb!L-!Tbjup!U-!Njzbub!Z!)2::3*!Tpnf!qjoftt!dbsf!boe!bo!fyqfsjnfoubm!bqqspbdi/!Kqo!Kpg!Qtzdi prm!63-473.476!)jo!Kbqbofsf*/!

Njdijn ps!B-!Tupof!Q!Drbvejp!T!)2::5*!Sfmbujpotijq!cfuxffo!uif!Bmqib!Buufovbujpo!Uftu!Tvckfdujwf!Tmffqjoftt!boe!Qfsgpsn bodf!Uftu!Qspdffejoh!pg!21ui!Tzn qptjvn!po!Ivn bo!Jbufsgbdf!344.347!)jo!Kbqbofsf*/!

REGIONAL CEREBRAL OXYGENATION AND BLOOD VOLUME RESPONSES IN HEALTHY WOMEN DURING SEATED WHOLE-BODY VIBRATION (WBV)

Rammohan V. Maikala[1], Yagesh N. Bhambhani[2]
[1]Liberty Mutual Research Institute for Safety, Hopkinton, Massachusetts, U.S.A.
[2]Faculty of Rehabilitation Medicine, University of Alberta, Edmonton, Canada

Introduction

Landstrom et al. (1985) suggested the possibility of cortical activation during exposure to WBV, however, it is not known how cerebral physiology (oxygenation and blood volume) responds in healthy women during different vibration frequencies. This study examined the role of backrest support and handgrip work on cerebral oxygenation and blood volume responses, during exposure to seated WBV.

Methods

Fourteen women (age: 23.9 ± 3.5 years) were randomly exposed to three frequencies of WBV (3, 4.5 and 6 Hz at approximately $0.9g_{r.m.s}$ in the vertical direction) on a customized vibrating base (Advanced Therapy Products, Inc., USA) in a seated posture on three separate days. On the first day, the subjects completed an aerobic fitness test until volitional exhaustion on an arm cranking ergometer (Cybex, MET 300, USA).

Each WBV session lasted 30 min (6 min baseline without WBV, 8 min WBV 'with' or 'without' backrest support, and 4 min recovery from WBV, 8 min WBV with 'opposite' backrest condition, and 4 min recovery following WBV). During 8 min WBV exposure 'with' and 'without' backrest support, subjects performed maximal voluntary rhythmic handgrip contractions with their right hand for 1 min using a dynamometer. To obtain regional oxygenation and blood volume responses, a NIRS sensor (MicroRunman, NIM, Inc., PA, USA) was placed on the anterior right frontal lobe just below the hair and close to fronto-temporalis region (Maikala et al. 2005).

Results

Baseline oxygenation and blood volume values were recorded during recovery from each WBV session of 'with' and 'without' backrest support. The physiological change in oxygenation and blood volume during each frequency (3, 4.5, and 6 Hz) for both backrest ('with' and 'without' a backrest) and workload (WBV only and WBV combined with rhythmic handgrip contractions) was calculated as the difference between the maximum values identified for each WBV condition of backrest and workload and baseline values (Maikala et al. 2005).

Three-way analysis of covariance with repeated measures (frequency, backrest, and workload) with a fully crossed design was used to evaluate the differences in the oxygenation and blood volume responses (measured in optical density [od] units). Peak oxygen uptake during

arm cranking was treated as the covariate. No three- or two-way interactions were significant ($P>0.05$). Only the main effects: frequency and workload reached statistical significance ($P<0.05$). Significant differences were observed in the oxygenation change between 3 and 6 Hz (0.0003 ± 0.04 od versus 0.065 ± 0.09 od, $P=0.022$), but not between 3 and 4.5 Hz (0.030 ± 0.06 od, $P=0.102$) and 4.5 and 6 Hz ($P=0.206$). Corresponding comparisons for the blood volume changes were significant: between 3 and 4.5 Hz (0.017 od $\pm$ 0.12 versus 0.07 ± 0.06 od, $P=0.008$) and 3 and 6 Hz (0.100 ± 0.09 od, $P=0.004$), but not between 4.5 and 6 Hz ($P=0.247$). Physiological changes were similar 'with' and 'without' backrest support (oxygenation: 0.031 ± 0.07 od versus 0.030 ± 0.07 od, $P=0.79$; blood volume: 0.063 ± 0.07 od versus 0.062 ± 0.12 od, $P=0.80$). Compared to WBV only condition, changes were higher during rhythmic handgrip contractions (oxygenation: 0.020 ± 0.07 od versus 0.042 ± 0.07 od, $P=0.000$; blood volume: (0.048 ± 0.06 od versus 0.078 ± 0.12 od, $P=0.015$)). Subjects' aerobic fitness influenced the oxygenation and blood volume responses during WBV ($P<0.05$).

Discussion

Compared to sitting without WBV, cerebral region showed increase in both oxygenation and blood volume responses at each frequency of WBV, implying an increase in neuronal activity due to WBV. Highest oxygenation and blood volume responses were observed during exposure to 6 Hz, suggesting women respond differently compared to men between the frequencies of 3 and 6 Hz (Maikala et al. 2005). An increase in response during handgrip contractions suggest that exposure to WBV in combination with physical activity might lead to much greater increase in cerebral activity due to functional motor stimulation. During vibration, Weinstein et al. (1988) suggested an increase in axonal transport due to direct stimulation of the brain, similar to the mechanism occurring during peripheral nerve injury, and the current evidence from exposure to WBV in different experimental conditions suggest that, increased neuronal activity subsequently results in increased perfusion to the pre-frontal cortex.

References

Landstrom, U., and Lundstrom, R. (1985). Changes in wakefulness during exposure to whole-body vibration. Electroencephalogr Clin Neurophysiol 61, 411-415.

Maikala, R.V., King, S., and Bhambhani, Y.N. (2005). Regional Cerebral oxygenation and blood volume responses to seated whole-body vibration. Eur J Appl Physiol. 95, 447-453.

Weinstein J., Pope M., Schmidt R., and Seroussi, R. (1988). Neuropharmacologic effects of vibration on the dorsal root ganglion – An Animal Model. Spine 13, 521-525.

HEALTH PERCEPTION IN WORKERS EXPOSED TO HAND-ARM VIBRATION: PREREQUISITE FOR PUTTING IN PLACE AN EFFECTIVE PREVENTIVE PROGRAM IN THE WORKPLACE

Alice Turcot
Institut national de santé publique du Québec, Direction de Santé Publique Chaudière-Appalaches, Barbara Tessier, Direction de Santé Publique Chaudière-Appalaches, Maria Alzate, Suzanne Bédard, Christian Bélanger, CSSS Montmagny-L'Islet

Introduction

Knowledge of risks from exposure to hand-arm vibrations is usually presented by clinicians and researchers from a medical and engineering point of view. There is a strong need to develop innovative health promotion programs for exposed workers. Risk perceptions by vibration exposed workers and HAVS (hand-arm vibration syndrome) affected workers are less well known. In 1983, Brubaker demonstrated that 75% of studied fellers thought that whitening of the fingers was part of the job and/or an unrelated nuisance, while only 25% believed it was a disease. [1]Grounds also showed that even though there were a very high number of forestry workers with white fingers, none considered quitting because of their condition. [2] It seems that many workers hesitate to declare the illness or believe they are less affected than they really are, perhaps from fear of losing their jobs and livelihood. [3] Risk awareness, on the part of exposed workers and their employers, as well as knowledge and acceptance of available preventive solutions are necessary steps before installing adequate preventive measures, whether organizational, behavioral or environmental. Workers need to understand fully the hazards and risks in order to be able to make informed decisions under uncertain conditions.[4] Prerequisites include the following: workers knowledge about the risk, their attitude towards it, which in turn, can be influenced by values, needs and interests. Also, knowledge and attitudes towards safety behaviour, organizational or environmental barriers must be taken into account. Our research focuses on these key elements, which help bridge the gap between health promotion research and practice.

Methods

A descriptive exploratory study is in progress with workers exposed to hand-arm vibrations. It uses qualitative methods that include focus group discussions with workers exposed to hand-arm vibrations, as well as individual interviews with other key informants (employers, health care professionals). An open-ended questionnaire was developed to collect qualitative data on perceived risks and solutions to prevent or reduce HAVS. Based on an integrated theoretical framework related to known determinants of behavior change, the analysis will focus on the following[5]:

1) knowledge of health effects, safety, well-being and/or quality of life
2) related beliefs about individual susceptibility and severity of consequences
3) attitude and values related to hand-arm vibration exposure
4) knowledge and attitudes towards exposure reduction, as well as perceptions of barriers and facilitating factors for these measures, in the workplace environment or otherwise.

Results

Preliminary research results indicate that several obstacles exist that need to be addressed, when putting in place preventive measures in the workplace. These include obstacles from the point of view of workers, employers, and health care professionals. We will present the underlying concepts and the theoretical framework necessary for setting up HAVS preventive programs in the workplace as well as the preliminary results of the research.

Discussion

We highlight the importance of taking into account determinants of behavioral change within a theoretical framework, while respecting the workers' and employers' perspective, when setting up HAVS preventive programs. "Health professionals must consult the people who are the intended target of health programs to determine their needs, problems, and aspirations concerning quality of life. If professionals do not take this vital step, health policies will remain sterile technocratic solutions to problems that may not exist or that hold a low priority in the minds of the people."[6]

References

[1] Brubaker R et al., (1983), Vibration white finger disease among tree fellers in British Columbia, Journal of Occup. Med., 25, no.2, 403-408.

[2] Grounds MD, (1964), Raynaud's phenomenon in users of chain saw, Med J Aust, 22, 279-272 cité in Pykkö et al, (1982), Longitudinal study of Vibration Syndrome in Finnish forestry workers, Vibration effects on the hand and arm in industry, Wiley Interscience, 157-167.

[3] Gemne G et al., 1983, The Stockhom Workshop scale for the classification of cold-induced Raynaud's phenomenon in the hand-arm vibration syndrome (revision of the Taylor-Pelmear scale), Scand J Work Environ Health, 13, 275-278.

[4] Nicholson PJ, (2000), Communicating occupational and environmental issues, Occup.Med. 50, 226-230.

[5] Committee on Communication for Behaviour Change in the 21st Century: Improving the Health of Diverse Populations, (2002) Board on Neuroscience and Behavioral Health, The National Academic Press, Washington, DC.

[6] Green Lawrence, Kreuter Marshall, (1991), Health promotion planning, An educational and Environmental Approach.

Podium Presentations

Session VI: Epidemiology, Standards Applications, and Prevention I

Chairs: Bernard Martin and Paul-Emile Boileau

SHOCK AND IMPACT ON NORTH AMERICAN LOCOMOTIVES EVALUATED WITH ISO 2631 PARTS 1 AND 5

Neil K. Cooperrider, Consulting Engineer
John J. Gordon, GMH Engineering

Introduction

The International Organization for Standardization (ISO) standard ISO 2631 [1,2] provides three methods for evaluation of human exposure to vibrations that contain occasional shocks or impacts. Part 1 of the standard specifies the running r.m.s. or maximum transient vibration method (MTVV) and the fourth power vibration dose value (VDV). Part 5 of the standard provides a method of computing the stress in the lumbar spine for humans exposed to multiple shocks. Alem et al [3] have reported application of these methods to data for tactical ground vehicles. This paper reports and compares VDV and spinal stress evaluations of more than 90 hours of vibration and shock measurements on North American locomotives engaged in through freight operations.

The measurements evaluated in this paper were obtained for full crew shifts on 19 freight locomotive runs on mainline track in locations from New York to California. The shifts ranged in duration from 187 minutes to 497 minutes. The average speeds for the shifts were from 21.0 mph to 54.6 mph. All measurements were made on locomotives hauling freight trains in regular revenue service.

Data Acquisition and Processing

The results reported here were computed using test data acquired from a tri-axial seat pad, accelerometer at a sample rate of 400Hz with an anti-aliasing filter corner frequency of 100Hz. The VDVs and the lateral and longitudinal spinal stress values were computed directly from the acquired test data according to the procedures specified and described in [1] and [2]. The vertical spinal stress values were computed by converting the as-acquired test data to a sample rate of 160Hz for input to the vertical spine model, as required in [2]. The conversion of the test data from the as-acquired sample rate of 400Hz to the required sample rate of 160Hz involved up sampling or interpolating the test data to an equivalent sample rate of 800Hz, band limiting the resultant data with a low-pass filter corner frequency of 60Hz and finally down sampling or decimating the 800Hz data to a sample frequency of 160Hz.

Discussion

The vertical VDVs computed according to [2] for the 19 shifts ranged from 2.68 to 9.33 $m/s^{1.75}$. In all but one case, the vertical values were greater than the values for the lateral or longitudinal directions. Note that the health guidance in [1] puts the lower boundary of the health guidance caution zone at a VDV value of 8.5 and the upper boundary at 17 $m/s^{1.75}$. The daily equivalent static compression dose computed following [2] ranged from 0.123 to 0.434 MPa. Health guidance provided in [2] states that there is a low probability of an adverse health effect if the daily dose is less than 0.5 MPa.

The daily equivalent static compression dose is plotted against the vertical VDVs for the 19 shifts in Figure 1. As expected, a linear correlation of the spinal stress with VDV is evident in the graph. Also note that although the highest VDV values exceed the lower health guidance boundary, all the compression dose values are well below the boundary for low probability of an adverse health effect with daily exposure over a lifetime of work.

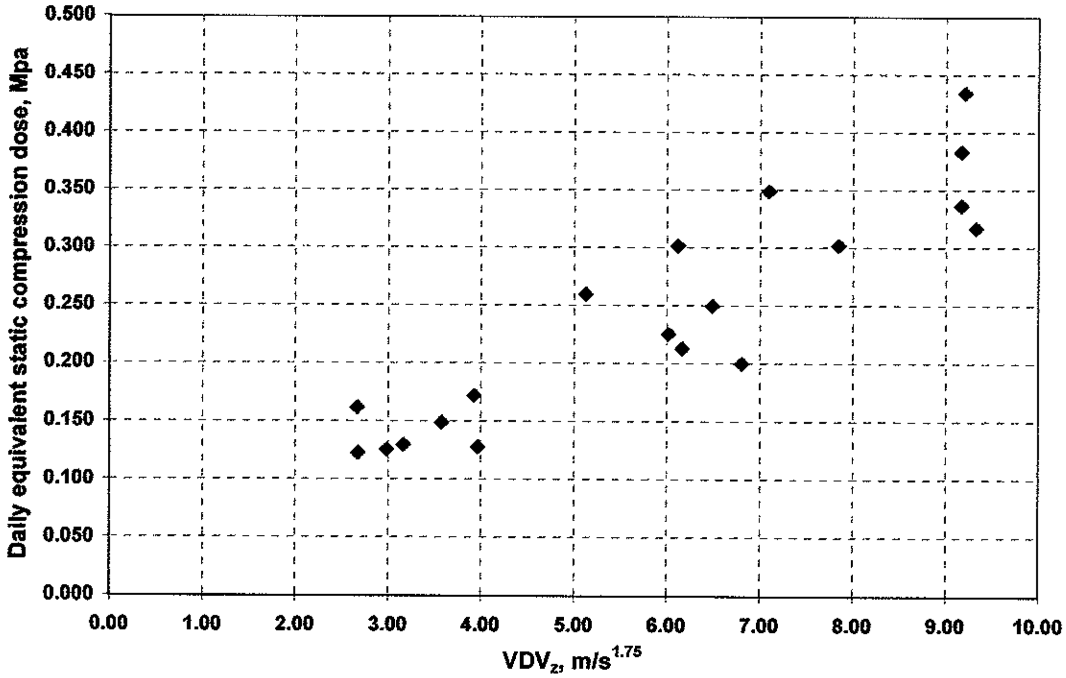


Figure 1. Daily static compression dose vs Vertical Vibration Dose Value

Conclusions

Evaluation of the data collected in the studies reported here following ISO 2631 suggests that the shock and impact exposure for locomotive crew members presents a low probability for an adverse health outcome. These results also indicate that, for locomotive shock and vibration, the health guidance for the VDV given in Part 1 of the standard is more stringent than the health guidance for spinal stress in Part 5.

References

1. International Organization for Standardization. (1997). Mechanical vibration and shock-Evaluation of human exposure to whole body vibration-Part 1: General requirements. ISO2631-1:1997
2. International Organization for Standardization. (2004). Mechanical vibration and shock-Evaluation of human exposure to whole body vibration-Part 5: Method for evaluation of vibration containing multiple shocks. ISO2631-5:2004.
3. Alem, N., Hiltz, E., Breaux-Sims, A. and B. Bumgardner. (2004). Evaluation of New Methodology for Health Hazard Assessment of Repeated Shock in Military Tactical Ground Vehicles. NATO RTO-Applied Vehicle Technology Symposium. RTO-AVT-110. Paper 7. pp 1-18.

REVISION OF ANSI S3.34 (2.70-2006) – GUIDE FOR THE MEASUREMENT AND EVALUATION OF HUMAN EXPOSURE TO VIBRATION TRANSMITTED TO THE HAND

Douglas D. Reynolds
Center for Mechanical & Environmental Systems Technology
University of Nevada Las Vegas, Las Vegas, Nevada, U.S.A.

Introduction

Intense vibration can be transmitted to the hands and arms of workers who use hand-held percussive or vibrating devices, tools, and work pieces. Continued habitual exposure to vibration directed to the hands can cause patterns of various symptoms associated with hand-arm vibration syndrome (HVAS). The International Organization for Standardization (ISO) first published ISO 5349 in 1986.[3] This standard specified methods for measuring and evaluating vibration directed into the hands from hand-held vibrating devices, tools, and work pieces. The American National Standards Institute (ANSI) published ANSI S3.34 the same year.[1] This standard was modeled after ISO 5349-1986 and specified methods for assessing exposure to hand-arm vibration.

The Parliament of the European Union has issued the European Union Human Vibration Directive-2002/44/EC, which specifies vibration daily exposure action values (DEAV) of 2.5 m/s^2 and daily exposure limit values (DELV) of 5.0 m/s^2. These values have generally been accepted by medical experts, scientists, and engineers in governmental agencies, research institutions, and industry in the USA and other countries.[2] When they are achieved, they will reduce the potential for the development of symptoms related to HAVS among workers exposed to hand-arm vibration.

Significant improvements in measurement and analysis instrumentation, miniature and subminiature accelerometers, and medical diagnostic and assessment protocols have being introduced since 1986 when ANSI S3.34 was first published. In response to these improvements and the introduction of the EU Human Vibration Directive, ANSI Working Group S2.39 developed the revision to ANSI S3.34, which has now been published as ANSI S2.70-2006.[2]

Method

ANSI S2.70 specifies the use of the hand-arm vibration measurement procedures outlined in ISO 5349, Parts 1 and 2.[2,4,5] It requires the measurement of ISO frequency-weighted acceleration values in three mutually orthogonal axes of vibration. These values are then vectorially added to obtain the vibration total value, a_{hv}:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad (1)$$

where a_{hwx}, a_{hwy}, and a_{hwz} are the measured r.m.s. ISO frequency-weighted acceleration values in the x, y, and z directions, respectively. If multiple vibration exposure events are experienced during a work day, the overall vibration total value is obtained from:

$$a_{hv} = \sqrt{\frac{1}{T}\sum_{i=1}^{n}\left(a_{hvi}^2\, T_i\right)} \qquad (2)$$

where a_{hvi} is the vibration total value of the ith operation, T_i is time duration in hours of the ith operation, n is the total number of operations, and T is total time in hours associated with the n

operations. Finally, the daily vibration exposure value, A(8), standardized to an 8-hour reference period, is obtained from:

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} \qquad (3)$$

where T_0 is the reference duration of 8 h.

ANSI S2.70 defines a value of A(8) equal to 2.5 m/s^2 as the Daily Exposure Action Value (DEAV).[2] The DEAV represents the health risk threshold to hand-transmitted vibration. "Health risk threshold is defined as the dose of hand-transmitted vibration exposure sufficient to produce abnormal signs, symptoms, and laboratory findings in the vascular, bone or joint, neurological, or muscular systems of the hands and arms in some exposed individuals.[2]" ANSI S2.70 recommends that a program be designed to reduce worker exposure to hand-transmitted when A(8) exceeds the DEAV to reduce health risks.

ANSI S2.70 defines a value of A(8) equal to 5.0 m/s^2 as the Daily Exposure Limit Value (DELV). [2] Workers who are exposed to hand-transmitted vibration at or above this level are expected to have a high health risk. "High health risk is defined as the dose of hand-transmitted vibration exposure sufficient to produce abnormal signs, symptoms, and laboratory findings in the vascular, bone or joint, neurological, or muscular systems of the hands and arms in a high proportion of exposed individuals.[2]" ANSI S2.70 recommends that workers not be exposed to A(8) values above the DELV.

Discussion

ANSI S2.70 is a timely and needed revision of ANSI S3.34. It gives the U.S. a modern standard that is in agreement with ISO 5349, Parts 1 and 2 and that has vibration assessment criteria that are accepted by medical experts, scientists, and engineers in governmental agencies, research institutions, and industry in the USA and other countries. ANSI S2.70 gives guidance for vibration exposure and health risks assessments, specifies methods for mitigating health risks associated with hand-transmitted vibration, and gives guidance for worker training and medical surveillance.

References

1. ANSI S3.34 (1986), Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hands. American National Standards Institute.
2. ANSI S2.70 (2006), Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hands. American National Standards Institute.
3. ISO 5349 (1986), Mechanical vibration — Measurement and evaluation of human exposure to hand-transmitted vibration. International Organization for Standardization
4. ISO 5349 (2001), Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – Part 1: General requirements. International Organization for Standardization.
5. ISO 5349 (2001), Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – Part 2: Practical guidance for measurement at the workplace. International Organization for Standardization.

STANDARD TESTS FOR SUSPENDED SEATS – CAN THESE CONTRIBUTE TO PROTECTION AGAINST WHOLE-BODY VIBRATION? – COMMENTARY ON HISTORICAL DEVELOPMENT AND CURRENT WORK IN CEN/TC231/WG9 (SEATING)

Richard Stayner
RMS Vibration Test Laboratory, Ludlow, U.K.

Introduction

Suspended seats perform two functions: Reduce effect of occasional large bumps; Reduce more continuous vibration at a lower level. The former needs high damping. The latter needs low damping. For most mobile work machines the inevitable compromise is generally better than a simple cushion seat, because that amplifies vibration at around 4 Hz which is a sensitive frequency for human vertical WBV.

Why have standard tests for seat suspensions?

- Seat suspensions are non-linear so any measure of performance depends on operating conditions. For comparison these need to be defined.
- Seat manufacturers need benchmarks for product development;
- Machine makers choose dynamic characteristics appropriate to their products;
- Occupational health specialists wish to control operator exposure to

Standard tests should be representative, repeatable and reproducible. These requirements are reviewed in relation to the history of seat test standards and the current position.

Current position and history

The current position is that we have standard tests for seats for agricultural tractors, earthmoving machinery, industrial (fork-lift) trucks. These tests comprise measurement of vibration transmission and of the rate of damping.

Current standards developed as the technology developed, starting around 1960:

1. Test on machine driven over standard surface[1].
2. Test on shaker reproducing standard surface.
3. Shaker input replaced by representative spectrum[2].
4. Human subject replaced by dynamic dummy. (Not yet settled).

Are standard tests representative?

The development process has gradually moved seat tests further from reality. 4 hr samples of work exposure suggest that seats do not **on average** provide large reductions of vertical WBV[3]. For **specific magnitudes** of vibration they can work well. For low vibration, performance is reduced by friction and for severe vibration by length of travel. Recent work has led to a new test to quantify how a suspension controls over-travel [9].

Are standard tests repeatable?

Tests involving driving a machine were never very repeatable, because the input could not be controlled very closely. Shaker tests can have very repeatable inputs, e.g. KAB Seating has just run a review that shows consistency over a ten year period.

Are standard tests reproducible?

In Europe, inter-laboratory tests gave unacceptable inconsistencies. Dynamic dummies are being trialled to replace human subjects, but even with these there can be 25% difference between laboratories. Current work of CEN Seating WG is aimed at comparing how different laboratories interpret the standard specifications, with the aim of improving these specifications. Then with dummies we should have reproducibility.

Comments

We have standard tests for seat suspensions that are repeatable. Work is in hand to try to make them more reproducible. The question remains: How helpful are such standard tests in protecting workers against harmful effects that are associated with WBV?

References

1. Matthews, J. (1966) Ride comfort for tractor operators IV: Assessment of ride quality of seats. J. agric. Engng. Res. 11 (1), 44-57.

2. ISO 7096 (2000) Earthmoving machinery – Laboratory evaluation of operator seat vibration. International Standards Organization, Geneva.

3. Scarlett, A.J., Price, J.S., Semple, D.A. and Stayner, R.M. (2005) Whole-body vibration on agricultural vehicles: evaluation of emission and estimated exposure levels. Research Report 321, Health and Safety Executive, ISBN 0-7176-2970-8.

EVALUATION OF SCRAPER OPERATOR EXPOSURE TO WHOLE-BODY VIBRATION IN THE CONSTRUCTION INDUSTRY: A TASK ANALYSIS

E.K. Gillin[1], A.Cann1, P. Vi[2], T. Eger[4], M. Hunt[1], A. Salmoni[3]
[1]Doctoral Program in Rehabilitation Sciences, University of Western Ontario, Canada
[2]Construction Safety Association of Ontario, Canada
[3]School of Kinesiology, University of Western Ontario, Canada
[4]School of Human Kinetics, Laurentian University, Ontario, Canada

Introduction

Kittusamy (Kittusamy & Buchholz, 2004) state that there have been few studies conducted to assess exposure to whole-body vibration (WBV) in the construction industry. They suggest that there is very little reliable data from the construction industry that characterizes exposure levels to various hazards including WBV or the health outcomes from such exposure and that there is a need for more exposure data. In a recent exploratory study of heavy construction equipment Cann (Cann, Salmoni, Vi, & Eger, 2003) looked at vibration levels for 14 different types of construction equipment. Eight of the 14 pieces of equipment tested exposed operators to levels of WBV that exceeded the recommended limits for an 8-hour period when comparing the measured VDV to the ISO 2631-1 standards. The purpose of the present research was not only to test a larger number of scrapers but also to investigate scraper operator exposure to whole body vibration (WBV) separately for each task.

Methods

33 scrapers were evaluated for WBV in a variety of residential and road construction projects. Testing equipment consisted of triaxial accelerometers that allowed vibration data collection in all three orthogonal axes, with the x-axis positioned to measure vibration in the anterior-posterior direction, the y-axis in the medial-lateral direction, and the z-axis in the vertical direction. Root mean square accelerations (aRMS), vibration dose value (VDV), crest factor, and maximum transient vibration values (MTVV) were derived from this software and exported to an Excel™ spreadsheet for later data analysis.

Test sessions for each piece of equipment lasted for approximately 20 minutes until at least three work cycles had been completed. Tasks included: idling while waiting for a bulldozer to push the scraper through the scraping phase, scraping, traveling loaded with dirt, dumping and traveling empty.

Results

Task breakdown by time reveals 25% of the work cycle was spent traveling fully loaded with dirt, 19% dumping, 21% traveling unloaded, 17% idling and 18% scraping. Calculation of aRMS vector sums gave values of 2.55 m/s^2 during loaded transport, 2.46 m/s^2 during dumping, 2.31 m/s^2 during unloaded travel, 0.55 m/s^2 during idling and 1.46 m/s^2 during scraping (see Table 1). The highest acceleration values recorded were found in the z-axis during fully loaded transport reaching an average aRMS over three work cycles of 2.55 m/s^2.

Table 1: Summary of WBV aRMS from the x,y,z axes n=33

aRMS (m/s^2)	Loaded	Dump	Unloaded	Idle	Scrape	Overall
X (m/s^2)	0.97	0.94	0.88	0.23	0.60	0.81
Y (m/s^2)	1.04	0.99	0.95	0.21	0.59	0.86
Z (m/s^2)	1.55	1.49	1.39	0.32	0.83	1.28
Vector Sum (m/s^2)	2.55	2.46	2.31	0.55	1.46	2.12

Discussion

The overall vector sum aRMS values exhibit accelerations well beyond the Commission of European Communities (CEC) recommended 8 hour levels. In a review of European Union whole body vibration exposure standards Griffin confirms the 8 hour action limit to be 0.5 m/s^2 and the 8 hour exposure limit of 1.15 m/s^2 (Griffin, 2004). Results are consistent with whole body vibration measurements from previous work. Accelerations are repeatedly in excess of maximal exposure limits recommended by ISO. This leads one to conclude that all scrapers will expose the operator to excessive levels of whole body vibration that may lead to injury or illness. There are researched methods that a scraper operator can do to decrease this risk. First, they can decrease speed while traveling loaded, dumping and unloaded. Second, they can ensure that tire pressure is at optimal levels. Third, they can maintain a healthy posture while driving.
However, the effect of such risk reducing factors is minimal. The solution to harmful vibration does not lie in wasting more money testing construction equipment to determine that it is exposing the user to potentially higher than recommended levels of vibration. The solution lies in the engineer's hands. Attacking this problem through better seat design is thought to enable a decrease of over 50% (Griffin, 1990). In addition, improving vehicle suspension, cab vibration absorption and engine mounts keeps solutions at the source of the problem versus at the operator.

Acknowledgements

The authors would like to thank the Workplace Safety and Insurance Board of Ontario for its generous grant and workers who participated in this research.

References

Cann, A. P., Salmoni, A. W., Vi, P., & Eger, T. R. (2003). An exploratory study of whole-body vibration exposure and dose while operating heavy equipment in the construction industry. Appl Occup Environ Hyg, 18(12), 999-1005.

Griffin, M. J. (1990). Vibration and human responses. In Handbook of Human Vibration (pp. 7). London: Academic Press Inc.

Griffin, M. J. (2004). Minimum health and safety requirements for workers exposed to hand-transmitted vibration and whole-body vibration in the European Union; a review. Occup Environ Med, 61(5), 387-397.

ISO. (1997). Mechanical Vibration and Shock-Evaluation of Human Exposure Whole-Body Vibration-Part 1: General Requirements. Genva: Switzerland: International Organization for Standardization.

Kittusamy, N. K., & Buchholz, B. (2004). Whole-body vibration and postural stress among operators of construction equipment: a literature review. J Safety Res, 35(3), 255-261.

CHARACTERISTICS OF WHOLE-BODY VIBRATION FREQUENCIES AND LOW BACK PAIN IN URBAN TAXI DRIVERS

Jiu-Chiuan Chen[1,2], Wen-Ruey Chang[3], Britt H. Hatfield[2], David C Christiani[2]
[1]Department of Epidemiology, University of North Carolina, School of Public Health, Chapel Hill, North Carolina, U.S.A.
[2]Occupational Health Program, Department of Environmental Health, Harvard School of Public Health, Boston, Massachusetts, U.S.A.
[3]Liberty Mutual Research Institute for Safety, Hopkinton, MA, U.S.A.

Introduction

Occupational exposures to whole-body vibration (WBV) at different frequency domains may differentially affect human comfort and the musculoskeletal system. Under this presumption, a frequency-based weighting scheme has been adapted in many widely accepted standards for WBV measurement. However, there is very little human data showing a direct link between WBV frequency and musculoskeletal disorders. We conducted an epidemiologic study to examine the association between WBV frequency and prevalence of low back pain (LBP) and to identify determinants of specific frequencies associated with LBP in urban taxi drivers.

Methods

The WBV frequency data were collected from 247 professional drivers (aged 44.6±8.3) who participated in an exposure validation study [1] of the Taxi Drivers' Health Study (TDHS) in 2000. [2] In accordance with the ISO 2631-1 (1997) methods, we measured the frequency-weighted acceleration over drivers' seat surface, under conditions representing randomly assigned destinations. We developed a WBV record-replay system at the Liberty Mutual Research Institute (LMRI) in Hopkinton, MA, USA. This system includes two tri-axial accelerometers (PCB Piezotronics, NY, USA), one RD-130T PCM data recorder (TEAC, Tokyo, Japan), and one LMWBV meter 2.0 (LMRI, MA, USA). Only the vertical axis of seat-surface WBV frequency was used in this study. To characterize the WBV frequency curve, we manually identified the presence of any peak within each of the following frequency range: <4, 4-10, 10-20, and >20 Hz. Information about the operating vehicles and driving environment was either collected from the vehicle registration record (manufacturer, year of make, transmission, engine size, etc.) or directly measured (wheel-base length, seat inclination, etc.). Structured interviews were conducted by an occupational physician to gather information on LBP that had led to medical attention or absence from driving in past year. We used multiple logistic regression to estimate the prevalence odds ratio (OR) associated with the presence of each index peak frequency, adjusting for age, body mass index, professional seniority, daily driving hours, seat inclination, and the intensity of predicted root-mean-square WBV exposure in m/sec^2. For any revealed WBV frequency that was associated with LBP, we constructed a multiple logistic regression model to identify the personal and vehicle characteristics associated with the presence of WBV peak within the indicated frequency range.

Results

Of the 236 (96% of 247) all male drivers who had WBV frequency data, 47% complained LBP in the past year. Of all classifiable frequency curves, the proportion of having an identifiable peak, respectively for <4, 4-10, 10-20, and >20 Hz, was 71%, 93%, 47%, and 56% respectively. Drivers whose frequency curves did not reveal the presence of peak frequency < 4Hz had the lowest LBP prevalence (37%). Results of multiple logistic regression showed positive associations between the presence of peak frequency <4 (p=0.06) or 4-10Hz (p=0.35) and increased 1-year prevalence of LBP, with estimated prevalence OR=1.98 (95% confidence [CI]: 0.98-4.01) and 1.74 (95%CI: 0.54, 5.59). No positive associations were found with the presence of peak frequency either at 10-20 or >20Hz. As average driving speed increased, the probability of having a low-frequency (<4Hz) peak on WBV curve increased in a quadratic-linear manner (p<0.001). Other significant determinants of the presence of a WBV peak frequency <4Hz included: engine size <1500c.c. (OR=1.72, 95%CI: 1.46, 9.70) and manufacturer (p<0.001). Our preliminary analyses did not suggest any statistically significant associations with other vehicle or drivers' characteristics.

Discussion

This was the first epidemiologic study linking LBP with WBV frequency profile obtained by directly measuring frequency during the exposure. Our preliminary analyses indicated that the presence of a low-frequency (<4Hz) WBV peak was associated with higher 1-year prevalence of LBP. Although we noted a positive association with the presence of a WBV peak near the resonance frequency of 4-6 Hz, the limited variability of the WBV frequency curve across the 4-10 Hz range, probably as a result of applying the ISO 2631-1 (1997) frequency weighting function, might have precluded the possibility of finding any statistically significant association. We also identified driving speed, engine size, and manufacturer as the most significant determinants of the presence of a low-frequency (<4Hz) WBV peak. Further analyses will examine the association of LBP with the estimated intensity of each WBV peak, and also to identify the determinants of any peak WBV intensity that correlates, if any, with LBP in urban taxi drivers. If the positive association between low-frequency (<4Hz) WBV and LBP was further confirmed, experimental research should look into the biomechanical effects and other pathophysiological changes related to WBV exposure at this frequency range.

References

1. Chen JC, Chang WR, Shih TS, et al. Using "exposure prediction rules" for exposure assessment: an example on whole-body vibration in taxi drivers. Epidemiology 2004; 15:293-9.
2. Chen JC, Dennerlein JT, Shih TS, et al. Knee pain and driving duration: a secondary analysis of the Taxi Drivers' Health Study. Am J Public Health 2004; 94:575-81.

INVESTIGATION INTO THE UNCERTAINTY IN MEASUREMENTS AND EVALUATION OF HAND-TRANSMITTED VIBRATION

Han-Kee Jang, Chi-Mun Song, Seok-In Hong, Seok-Hyun Choi
Institute for Advanced Engineering, Yongin, Korea

Introduction

Accurate measurement and evaluation of hand-transmitted vibration from a power tool is an important issue for tool manufacturers, because they are obliged to develop low-hazard power tools for workers. The International Standard ISO 5349[1] dictates a systematic procedure for the measurement and evaluation of hand-transmitted vibration. However, the uncertainty in this measurement is too large for manufacturers to apply such data to the design and modification of power tools. There can be several sources of this uncertainty in such measurements; e.g., operator-dependent, power tool-dependent, and operational conditions (see Table 1). For a manufacturer to characterize the exposure of a power tool's use to a given level of vibration, the relationship between these uncertainty factors and the measured vibration must be elucidated. In this study, we investigated the effect of several factors on the uncertainty in measurements.

Table 1. The possible sources of an uncertainty in a measurement.

Tool	Operator	Operating condition	Instrumentations
Tool Grit/Tip/Insert Installation	Stature and weight Muscular strength	Posture Applying forces	Accelerometer Data processing device

Methods

In this study, some of the factors in Table 1 were selected for examination, and their effect on the measured variation was quantitatively investigated. Three tools from the same manufacturer were sampled at random in our experiments, and each of five of the same type of insert (disks or tips) was installed into each tool. Although each of the tools and inserts were of the same design and were made by the same production process, they differed from one to another, which can be a source of the variation in the measured vibration.

Three human subjects participated in our experiments, which were carried out as stated in ISO 5349. The subjects were asked to maintain their posture, and the applied force was kept as constant as possible. The applied force was monitored using an indirect method, where vibration energy was displayed in real time during the experiment using a three-axis accelerometer attached to the work piece at a specified point. The appropriate range of the applied force was predetermined to cover the range of real work operations. The engineering tolerance between the inner diameter of a grit disk and the outer diameter of the tool shaft leads to an eccentricity of the mass at the center of the disk. The degree of eccentricity varies with installation, and this is another source of uncertainty. In our study, the effect of this eccentricity was investigated by carrying out repeated assembly and disassembly of an insert.

Human exposure levels of hand-transmitted vibration were measured in 45 combinations of the three subjects using three tools of the same make, and five inserts of the same make for each of the three types of tool studied: a 7" and a 4" grinder, and a die grinder. Each measurement was performed following the procedure listed in ISO 5349. Data acquisition for each case was made over a period of five minutes involving five repeated one-minute measurements.

Results

Table 2 shows the variation in human exposure levels to hand-transmitted vibration, a_{hv}, for the selected factors. For example, the 7" grinder showed a variation of 13.7% for our subjects using the 15 tool and insert combinations. For the three types of tool, the effect of the variation among the tools, which was closely related to the quality of the product, was the most dominant factor. Variations in the vibration according to subject varied from 11.7% to 13.7%, which seems reasonable, because the applied force was monitored and controlled during the measurement. Variations according to the insert are possibly caused by irregularities in the insert and/or installation. Variations in the measurements according to installation were investigated in a separate experiment.

Table 2. Variations in human exposure levels of hand-transmitted vibration with different tools, inserts, and subjects.

	Factor		
	Subject	Tool	Insert
7" Grinder (plus grit grinding wheel) grinding stainless steel	13.7%	40.3%	14.7%
4" Grinder(plus grit grinding wheel) grinding stainless steel	11.7%	18.6%	9.5%
Die grinder (plus rotary cutter) grinding stainless steel	13.4%	18.9%	16.4%

Discussion

We have investigated the effect of several factors on the uncertainty in measurements of hand-transmitted vibration. Among the three major factors studied, the variation according to the tool used was the most dominant factor, even though this was limited. The variation according to subject showed a consistent value of 11.7% to 13.7% for the three types of tool studied. The variations according to insert had two causes: one was due to the irregularities between the inserts, and the other was due to the eccentricity of the rotation, which is currently under further investigation.

To compare human exposure levels to vibration in different tools, which is necessary for the selection of better tools, more research into the effect of the factors that influence the uncertainty should be carried out.

Reference

ISO 5349-1, 2001, Mechanical vibration—Measurement and evaluation of human exposure to hand-transmitted vibration Part 1: General requirements, International Organization for Standardization, Geneva.

Podium Presentations

Session VII: Biodynamics II

Chairs: John Wu and Kumar Kittusamy

A PORTABLE MEASUREMENT SYSTEM FOR THE ASSESSMENT OF TIME WEIGHTED AND IMPULSIVE EXPOSURES TO WHOLE BODY VIBRATION

Peter W. Johnson and Jim Ploger
University of Washington, Department of Environmental and Occupational Health Sciences, Seattle, Washington, U.S.A.

Introduction

Bus drivers represent a large segment of the US transportation industry and research has shown an association between exposure to Whole Body Vibration (WBV) and the high rates of low back disorders. Impulsive WBV exposures have been recognized as a risk factor for low back injury and new guidelines exist for their measurement and assessment (ISO 2631, Part 5). Methods to accurately and better characterize the impulsiveness of WBV along with the temporal patterns of the exposures are needed. The development of a hardware and software system to measure continuous TWA and raw, impulsive WBV exposures and the design of a subsequent study are presented.

Methods

Using two Larson Davis HVM 100 as accelerometer amplifiers, small external batteries, and a Pocket-PC (PDA) with 1 Gb of compact flash memory, we can collect up to 16 channels of data for a full day 600 Hz. Tri-axial WBV exposures will be measured and characterized at the frame of the bus and at the driver/seat interface (seatpad accelerometer). Using a repeated measures design, 20 bus drivers will drive on selected routes which include both city streets and highways, and within and between subject components of variability and exposure determinants related to the bus, bus seat, the bus driver, and the route will be identified. Global Positioning System (GPS) data will also be collected and integrated with the WBV exposure data to facilitate the identification of the location, velocity and type of road associated with high average TWA and impulsive WBV exposures. This system may be used to develop administrative (alter speed and/or route of bus, systematically vary type of routes) and/or engineering controls (identify and trigger the need for street repair) to reduce high WBV exposures.

Results

Our portable Pocket-PC based data acquisition system is up and running and we can collect seven channels of WBV data (seat pan tri-axial accelerometer, bus frame tri-axial accelerometer and GPS data) continuously for a full shift. The software analysis of the data is complex but nearing completion. We have incorporated the vibration dose calculations from ISO 5321, Part 5 and have obtained a Matlab-based routine to appropriately weight the continuous signals.

Discussion

In summary, the measurement of WBV is complex but new technologies open avenues of collecting and assessing WBV exposures that were previously not possible. The standardization of impulsive WBV exposure assessment methods is needed to further the discipline and better enable comparisons across studies.

INFLUENCE OF BACK SUPPORT CONDITIONS ON THE ABSORBED POWER OF SEATED OCCUPANTS UNDER HORIZONTAL VIBRATION

S. Mandapuram[1], S. Rakheja[1], Shiping. Ma[1], P.-É. Boileau[2]
[1]Concordia University, Montréal, QC, Canada
[2]IRSST, Montréal, QC, Canada

Introduction

The absorbed power (P_{Abs}) has been suggested as a better measure of human responses to whole-body vibration, since it relates to the cumulative energy dissipated by the body exposed over a given duration. Moreover, unlike the other measures, the P_{Abs} can adequately account for the intensity of exposure. Although, the vast majority of off-road vehicles impose considerably severe vibration along the horizontal axes, the vast majority of studies on biodynamic response characterization consider only vertical vibration. Only a few studies have reported P_{Abs} responses of the seated human body exposed to horizontal vibration and the major contributing factors [1]. This study aims to characterize the P_{Abs} responses of seated human subjects to horizontal (uncoupled x- and y-axis) vibration as functions of the vibration intensity, subject mass, seat height and the, type of back support.

Methods

Experiments were conducted using a rigid seat with an adjustable backrest inclination and seat height. The seat was installed on a horizontal vibration simulator and the forces at the seat base and the backrest were measured by three-axis force plates. Two single-axis accelerometers were installed on the seat back and the platform, oriented along the axis of motion. The experiments were performed using three different seat heights (350, 390 and 410 mm), back support conditions (NB- no back support and sitting erect; Wb0- Upper body supported against a vertical back support; and WbA- back supported against an inclined backrest, while sitting relaxed) and three different magnitudes of broad band excitations in the 0.5-10 Hz frequency range (0.25, 0.5 and 1 m/s^2 rms acceleration under x-axis and y-axis, applied independently). A total of 8 healthy adult male volunteers with total body mass ranging from 59.4 kg to 92 kg and aged between 21-51 years took part in the experiments. The subjects were seated with their hands in lap, and feet supported on the moving platform for each posture. Each measurement was repeated 2 times, while the data were analysed using a bandwidth of 50 Hz and frequency resolution of 0.0625 Hz.

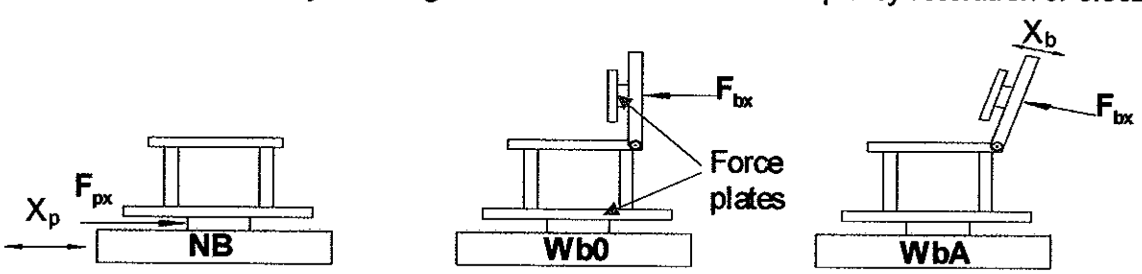


Fig 1: Back support conditions used in the study.

The data were analyzed to derive the absorbed power characteristics of the body at both seat pan and backrest interfaces, while the coherence among the measured forces and accelerations were

particularly monitored. The P_{Abs} of the seated body subjected to x- and y-axis vibration were computed in the one-third octave bands, while the total power was derived through integration of the real component of the force and velocity cross-spectrum under each test condition.

Results and Discussions

The measured absorbed power responses suggested significant inter-subject variability, irrespective of the experimental condition employed, while the total P_{Abs} showed nearly quadratic relation with the excitation magnitude. The seat-buttock interface P_{Abs} responses obtained for all the subjects seated assuming the NB posture and exposed to x- and y-axis vibration consistently revealed distinct peaks in the bands with center frequencies of 0.63 and 1.25 Hz. These frequencies are comparable with those observed from reported studies on P_{Abs} and APMS responses [1, 2]. The P_{Abs} responses revealed strong influences of the back support condition, apart from the vibration intensity under x-axis vibration, while the effect of seat height was observed to be small. Under y-axis vibration, the contributions due to back support were relatively small (Fig. 2).

Sitting with inclined back support (WbA) resulted in the peak P_{Abs} response in the 2.5-4 Hz bands under x-axis vibration, while the magnitude of the peak in the 0.63 Hz band diminished most significantly. The P_{Abs} derived at the backrest also revealed similar trends in magnitude and the corresponding frequency under x-axis vibration. The magnitude of the peak P_{Abs} measured at the back rest was around 50-60% of that measured at the seat pan, suggesting important interactions of the upper body with the backrest (Fig. 2). The WbA posture showed lower power absorption by the body when compared to that with the Wb0 posture, which can be attributed to more stable upper body posture when supported by an inclined backrest. Total P_{Abs} derived from the seat pan and the backrest measurements under x-axis motions showed good correlations with the body mass ($r^2 > 0.8$ and 0.7, respectively). The intermittent loss of contact of the upper body with the backrest resulted in relatively lower correlation with the body mass

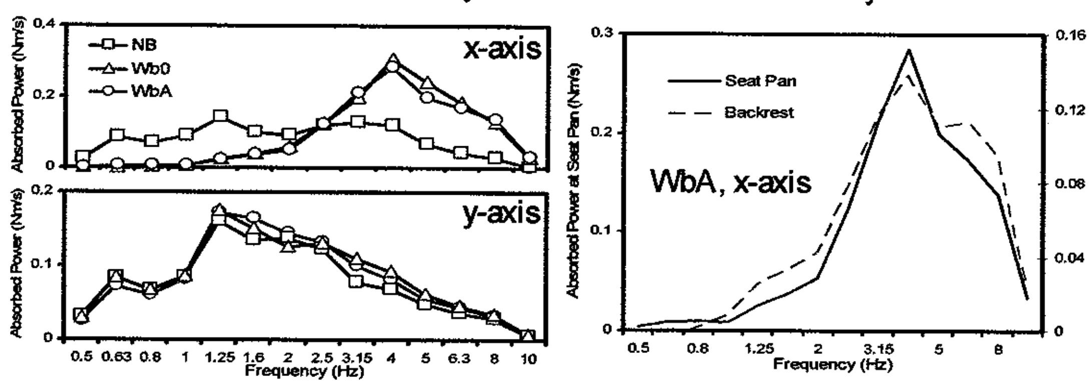


Fig. 2: Influence of back support condition on the absorbed power responses.

References

1. R. Lundström and P. Holmlund (1998) Absorption of energy during whole-body vibration exposure. Journal of Sound and Vibration 215(4), 789-799.
2. S. Mandapuram, S. Rakheja et al (2005) Influence of back support conditions on the apparent mass of seated occupants under horizontal vibration. Industrial Health, (43), 421-435.

A MULTI-BODY DYNAMIC BIOMECHANICAL MODEL OF A SEATED HUMAN EXPOSED TO VERTICAL WHOLE-BODY VIBRATION

A. Pranesh[1], S. Rakheja[1], R. Demont[2]
[1]CONCAVE Research Center, [2]Department of Exercise Science
Concordia University, Montréal, Québec, Canada

Introduction

Ethical concerns of in-vivo procedures and poor repeatability of non-invasive techniques have been major limitations in estimating vibration-induced spine loads through experiments. The biodynamic models of seated human body exposed to whole-body vibration (WBV) have evolved for defining the frequency-weightings, enhancement of human responses to WBV, and developing anthropodynamic manikins for seating assessment activities. The widely reported mechanical-equivalent models, solely based on through- or to-the-body biodynamic response functions, do not seem to resemble the biomechanical structure and do not yield information on the dynamic loading and deflections of segments of concern, namely the spine. On the other hand, biomechanical models with representative anatomical structure and anthropometry are being attempted to simulate segmental movements and the coupling effects, using Finite elements (FE) or multi-body dynamics (MBD) formalisms, which could provide important insights into the inter-vertebral forces [1]. While the FE models pose considerable complexities primarily related to characteristics of the bio-material properties, the MBD technique with discrete rigid bodies offers the flexibility to create multi-segment models with relative ease and lower computational cost. In this study, a preliminary multibody dynamic model of a seated human body exposed to WBV along the vertical direction is formulated using MSC/ADAMS software. The model validity is demonstrated by comparing selected responses with the available measured data.

Methods

The seated human is represented by nine rigid body segments, including: head, neck, thoracic and lumbar torso, pelvis, hands and thighs, as shown in Fig. 1. The rigid bodies are coupled through different rotational and translational joints, some of which are force elements to allow vertical translations and sagittal–plane rotations of the segments. The measurements of transmission of vertical vibration through-the-body generally require subjects to voluntarily maintain a vertical head position to reduce head-accelerometer orientation errors. The head–neck–shoulder joint is thus considered to be rigid. The shoulders are assumed to be rigidly attached to the thoracic segment.

The torso is made up of three (upper, middle and lower) segments connected by visco-elastic revolute and translational joints to permit relative pitch and vertical motions. The forces and torques generated by the joints are derived assuming linear stiffness and damping properties, which were identified from published studies. The pelvis is connected to the rigid seat by similar elements representing the visco-elastic properties of the buttock tissues. The two thighs are rigidly connected to the pelvis, while the segment masses are chosen from the anthropometric data for the 50^{th} percentile male subject.

The initial model parameters for the joints were obtained from [2]. The model was analyzed to determine the force-motion relationship at the buttock-seat interface expressed in terms of

apparent mass (AM) and through-the-body vibration transmission, expressed in terms of seat-to-head acceleration transmissibility (STHT), under a swept-sine vertical acceleration. Normal mode analysis was also performed to study the segment motions and resonant frequencies.

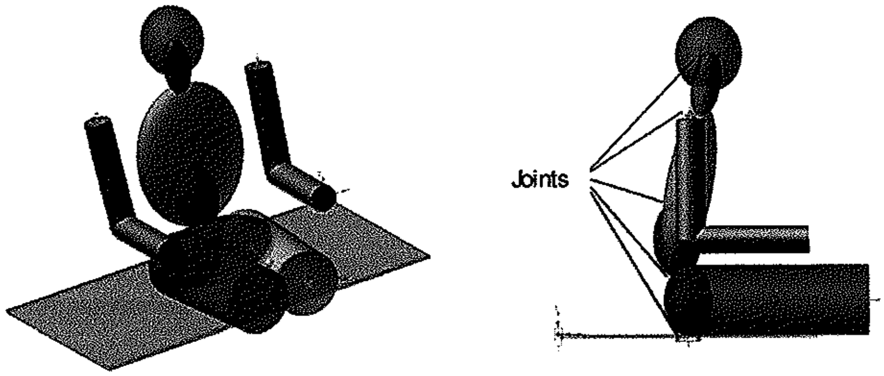


Fig. 1: A multi-body formalism of the seated body.

Results and Discussion

The model validity was initially examined by comparing the AM and STHT magnitude and phase responses with those reported in ISO 5982 [3] and Paddan and Griffin [4]. The results showed poor agreements between the model and reported responses, while the frequencies corresponding to the peak magnitudes were quite close. Normal mode analysis revealed two significant modes: upper-body pitch near 2 Hz, thoracic translation and pitch about the lumbar near 6.6 Hz. Both the AM and STHT responses showed peak magnitude near 4 Hz, while a relatively smaller magnitude peak was observed near 2 Hz. These frequencies agree well with those observed from the biodynamic responses under vertical and horizontal WBV, respectively. The discrepancies in the response magnitudes, however, suggested the need for verification and/or identification of suitable parameters for all the joints. An optimization-based parameter identification technique is thus applied with limit constraints around the reported values to enhance the validity of the model. The results suggest that the model parameters could be identified to match the AM and STHT responses, reasonably well. The feasibility of the resulting model in predicting the relative movements of segments and spine loads could then be explored.

References

1. Fritz, M. (1998) Three-dimensional biomechanical model for simulating the response of the human body to vibration stress. IEEE Med. Bio. Eng. and Comp., 36, 686–692.
2. Amirouche, F.M.L., Ider, S.K., (1988). Simulation and analysis of a biodynamic model subjected to low accelerations–a correlation study. J. of Sound and Vibration, 123 (2), 281–292.
3. International Organization for Standardization ISO 5982 (2001). Mechanical vibration and shock – Range of idealized values to characterize seated-body biodynamic response under vertical vibration.
4. Paddan, G.S., Griffin, M.J. (1998). A review of the transmission of translational seat vibration to the head. J. of Sound and Vibration, 215 (4), 863–882.

ASSESSMENTS AND REFINEMENTS OF AN ANTHROPODYNAMIC MANIKIN FOR SEATING DYNAMICS APPLICATIONS

S.K. Patra[1], S.Rakheja[1], P.E.Boileau[2], H.Nelisse[2], A. Natani[3]
[1]CONCAVE Research Center, Concordia University, Canada
[2]Institut de recherche Robert-Sauvé en santé et en sécurité du travail du Québec, Canada
[3]Indian Institute of Technology, Mumbai, India

Introduction

The current laboratory methods for assessing the vibration attenuation performance of seats involve repetitive trials with a number of human occupants, and raise certain ethical concerns. Moreover, the measurements with human subjects yield considerable variability in the data. Alternatively, several anthropodynamic manikins have been developed for effective assessments of the coupled seat occupant system [1]. The effectiveness of a manikin in predicting the response of a coupled seat-occupant system lies in its ability to reproduce the biodynamic response of the seated human body in terms of force-motion relationship at the body-seat interface, such as apparent mass (APMS). A number of prototype manikins have thus been developed on the basis of biodynamic characteristics of vertical vibration-exposed seated occupants of different body masses in the vicinity of 5^{th}, 50^{th} and 95^{th} percentile male population. This study concerns with the analysis of a passive prototype manikin to enhance its ability to reproduce the idealized APMS response characteristics of the vibration-exposed seated human subjects defined in ISO-5982[2] for mean body masses of 55, 75 and 98 kg.

Methods

The APMS responses of a prototype anthropodynamic passive manikin were thoroughly characterized in the laboratory under different excitations and body mass configurations. The manikin was designed with sufficient flexibility to configure mechanical-equivalent models corresponding to seated body masses of 55, 75 and 98 kg, by adding/removing specified masses and springs (Fig. 1). The manikin, configured for a specific body mass, was positioned on a rigid seat without a backrest, which was fixed to the force platform of a whole-body vertical vibration simulator. The simulator was programmed to synthesize random vertical vibration with flat acceleration power spectrum in the 0.4-20 Hz frequency range with two different magnitudes: 1 and 2 m/s^2 overall rms acceleration. The total static and dynamic forces of the manikin to and the seat were measured using the force platform, while a single axis accelerometer was installed on the seat pan to measure acceleration due to vertical excitation. The measured data was appropriately corrected for the rigid seat inertia force, and the apparent mass

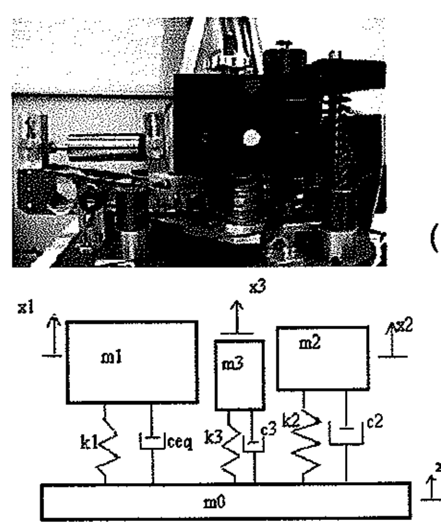


Fig. 1: A pictorial view and mathematical model of the manikin